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Corrosion

devoted entirely to
CORROSION
Research and Control

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CONTENTS

THIS MONTH'S COVER

• *Interior of Brewhouse at Gulf Brewing Co., Houston, Texas, showing Cereal Cooker, Mash Tun and Brew Kettle. Durability of equipment is only one part of the corrosion problem encountered in the brewing industry, as well as the allied industries of distilling and food processing. Of utmost importance is the use of proper alloys to assure freedom from contamination of the product, preservation of body, color and taste.*

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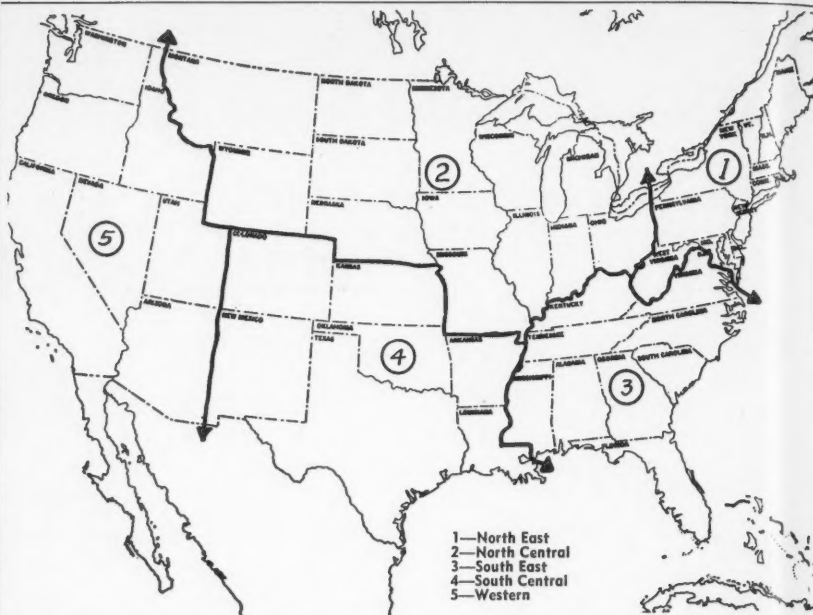
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A Message from Your Officers

This Month's Contributor

D. E. STEARNS, Director Representing Associate Membership

As ONE of the Directors representing the Associate Membership, it might seem that "Practice" would be a fitting theme for this brief message. However, my interest in the Association commenced at the very beginning, and my first endeavor was as one of the Active Membership. In those most important early days of the Association when general objectives, finances and the establishment of policies were of primary consideration, there came the need for an Emblem to stand for the principles of the group.

Emblems are a sort of combination of being born and being made—"born" from a thousand thoughts, some of which go trailing away into early oblivion—"made" from combinations of such imagery into crystallizations that become concrete and expressive of ideals. The words Corrosion Control were selected as representing the prime general objective of our Association. These words are therefore given prominence as the outstanding motif.

Heat is part of everything and plays great prominence in all industries. The representation of heat, and of all industry inferentially, is incorporated into the Emblem in the form of the simple flame—two of such serving as enclosures for the words Corrosion Control. The flames suggest gas and oil, which, taken together with coal also burning as a gas, represent the world's most important industrial commodities serving all industry, great and small. The two flames are drawn together at the top to form a central enclosure having shape as a modified spherical triangle suggesting the sphere—as the world—as the universe without limit.

The words "science" and "theory" taken together represent man's thinking and his resultant half-understandings and understandings of the laws of nature, its fixed manifestations and its seeming vagaries. Out of this background of the searching mind, then, comes the star of wisdom to shine forth and cast the light of understanding on "practice." Thus pure "science"—the laws of nature," "theory"—the ever-searching imagination of man—result in "practice," which "Protects Industry" by Corrosion Control.

All corrosion is electrical or chemical or electro-chemical, so we have the negative and positive representations, — and + respectively, as a tie-in to this phenomena. It will be noted that the negative sign is below the word "Corrosion," of a negative nature, i.e., unwanted; while the positive sign is below the word "Control," of a positive nature, i.e., wanted.

All of the Emblem's features as above described are underwritten in formal style by "NATIONAL ASSOCIATION OF CORROSION ENGINEERS, Organized 1943."

Study of the sciences and the resultant development of theory into practices to control corrosion should be conducted with ethical considerations on the part of all Members so that the prestige of NACE will grow stronger and more lasting as its history is made a little brighter with the passing of each new day. In the light of science all of mankind is humble and subservient. We do not make Nature's laws; we can only strive to learn and use them.

THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS

is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

(a) to promote scientific research in determining the causes of corrosion and methods of its control with respect to theory and practice.

(b) to provide a means of exchange of knowledge and ideas among those individuals actively engaged in the control of corrosion.

(c) to promote methods of control of corrosion.

(d) to promote standardization of terminology, methods, equipment and design in the development of methods of corrosion control.

(e) to foster cooperation between individaul owners of metallic structures in the solution of their joint corrosion problems.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers are nominated by (1) the Board of Directors, or (2) a quorum of at least 25 members, and elected by the membership.

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 905 Southern Standard Building, 711 Main Street, Houston 2, Texas.

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The Resistance of Alloys to Corrosion During the Processing of Some Foods*

*By J. F. Mason, Jr.**

IT IS THE PURPOSE of this paper to present the results of a number of miscellaneous plant and laboratory corrosion tests in the handling and processing of foodstuffs which have not already been published by The International Nickel Company. The corrosion resistance of material for pea, corn and tomato processing and the resistance of pure nickel and Inconel to corrosion by milk are discussed in detail in Inco technical bulletins T-28 and T-26, respectively. Additional data on the corrosion resistance of metals in the production of, and the effect of metals on, wines, distilled liquors and beers are given in Bulletin TS-6. Copies of these publications may be had on request.

The durability of equipment is only one part of the corrosion problem in food processing plants. Of at least equal importance are the possible effects of corrosion products on the quality of the products. In this connection, it has been found that nickel equipment as it is used in food processing is non-toxic. This statement is based on the results of several investigations made to determine the safety of using nickel equipment in the preparation of foods. An excellent summary of the situation was made by Drinker, Fairhall, Ray and Drinker[1] of the Department of Physiology, Harvard School of Public Health, who supplemented a study of the work of other investigators by tests of their own.

Similar research by Titus, Elkins, Finn, Fairhall and Drinker[2] has established also that the chromium-nickel-iron alloys (stainless steels) are fully acceptable from the hygenic standpoint for food preparation utensils.

It was further demonstrated by the work of Pratt[3] at the University of Rochester that nickel does not catalyze the destruction of vitamins in milk, one of the most perishable of foods. In his studies he compared milk containing on the average about 15 ppm of nickel with milk containing no nickel and his principal conclusion was that nickel dissolved from a nickel vessel did not destroy or catalyze the destruction of vitamins A, B or C during the pasteurization process.

* Corrosion Engineering Section, Development & Research Division, The International Nickel Company, Inc., New York, New York.
★ A paper presented at the annual meeting of NACE in St. Louis, Mo., April 5-8, 1948.

Additional investigations by Ziels and Schmidt[4] have also established that nickel is superior to most, if not all, other metals with respect to the absence of catalytic effects on the development of rancidity in fats and oils during steam deodorization, which is one of the most critical steps in the quality processing of edible oils and shortenings.

Heat Transfer

In addition to corrosion resistance and effect of metals on the product, another factor that should be taken into consideration in the selection of materials for food processing equipment is heat transfer. A large percentage of food processing operations involves heating or cooling something. Consequently, the materials used to hold the product and separate it from the heating or cooling media should not interfere too much with the transfer of heat. It is, of course, true, but not always recognized, that the resistance to heat flow offered by a metal wall is only one of several resistances which include, of greatest importance, films of the substance being heated, or of the heating medium which cling to the metal wall. Furthermore, there may be solid films of corrosion product, scale or baked-on substances which increase the resistance to heat flow.

Where the sum of all the resistances to heat flow is high, that of the metal may be of insignificant importance and the choice of metal will not have much effect on the overall rate.

In the food processing industry about the only equipment where the total resistance to heat flow is low

enough to make that of the metal itself appreciable are steam jacketed kettles and certain high velocity heat exchange apparatus, such as multi-tubular heaters and coolers. With tubular apparatus the gage of the metal tubes is relatively thin so that the maximum difference between the materials of highest conductivity, silver and copper, and those of low conductivity, stainless steel and Inconel, is rarely more than about 10 percent and often negligible. This is also true of heating coils.

In the case of steam jacketed kettles, the gage of metal is often fairly thick — one-eighth-inch or more — and since the overall rate of heat transfer is high — more than 400 Btu's per square foot per degree F. per hour—the effect of the metal itself may be appreciable. In a particular case it was found that water could be boiled in a copper kettle in six minutes, in a nickel kettle in seven minutes, whereas an Inconel or stainless steel kettle required twelve minutes.

Method of Test

Comparatively few quantitative tests have been published on the relative corrosion resistance of metals and their suitability for particular foodstuffs. Especially is this so in the case of alloys. Comparison with other possible metals has rarely been made and lack of standardization of testing conditions renders comparison difficult. In our field investigations, use was made of the spool-type specimen holder which permitted the simultaneous testing of a large number of metals and alloys in operating equipment under
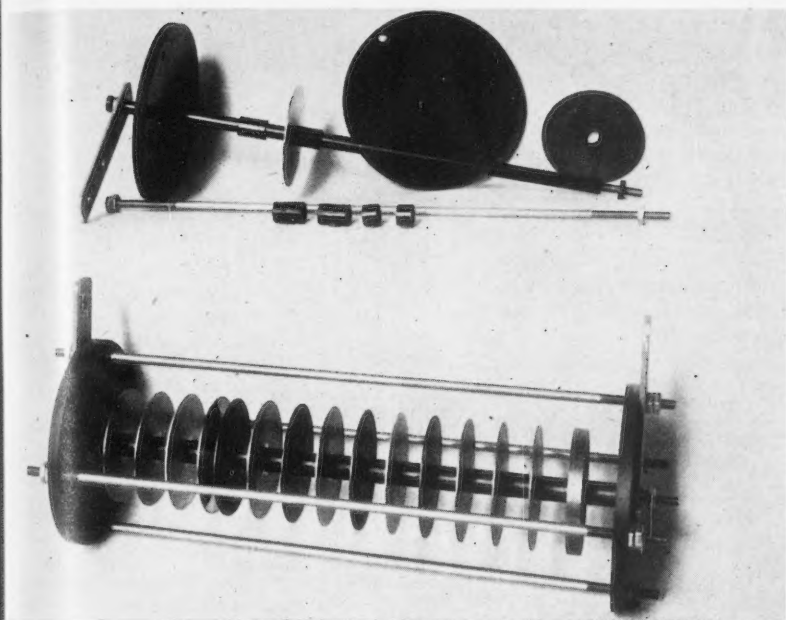
Figure 1—Spool type specimen holder used in testing corrosion of metals. Monel used for center spindle and tie rods.

the actual conditions of service, thus giving direct comparisons of the relative performance of the various materials studied. The testing device is illustrated in Figure 1.

This method of test was substantially in accord with ASTM Recommended Practice for Conducting Plant Corrosion Tests, A224-41.[5] Briefly, the assembly consisted of previously cleaned and weighed specimens of the several metals and alloys to be tested, mounted on the spool-type holder with non-metallic parts of bakelite or porcelain to separate and insulate the specimens from each other and from the metallic parts of the holder. Two similar specimens of each material were included on each spool. The completed

test assemblies were fastened firmly in place in the desired test locations in operating plant equipment and allowed to remain for sufficient lengths of time to give reliable indications of corrosion behavior. In some instances, also, the duration of the several exposures was determined by the cycle of processing operations which included cleaning of the test pieces as the equipment was cleaned and sterilized in the ordinary way. Each of the test specimens used had an exposed area of 0.5 square decimeter.

Upon completion of tests, the spools were removed, dismantled and the specimens examined, cleaned of all scale and corrosion product, and reweighed. From the weight

losses, areas of specimens and duration of exposure, the corrosion rates were calculated in terms of milligrams per square decimeter per day (mdd), and these rates transposed to inch penetration per year (ipy), the unit used in the accompanying tables. This unit is based upon the assumption of uniform corrosion in practice from one side of the metal only. The rate shown for each material is the average of the two specimens included in each test. In addition, each specimen was examined for cracking, pitting, and other forms of local attack. Where pitting or local attack occurred, depth of the five or ten deepest pits was measured microscopically or with a depth gauge. In the accompanying tables maximum depth of pitting is reported, where it occurred.

Nominal compositions of the metals and alloys included in one or more of these tests are shown in Table I.

Fruit Juices and Syrups

Table II gives the results of a number of plant and laboratory corrosion tests on Monel, nickel, Inconel and 18-8 stainless steel in a variety of fruit juices and syrups under different conditions of exposure. Generally, it will be noted that the materials tested performed satisfactorily and this is borne out in practice since they are used rather widely for equipment in the processing, storage and dispensing of fruit prod-

TABLE I

NOMINAL COMPOSITIONS OF METALS AND ALLOYS USED IN CORROSION TESTS

MATERIAL	Nickel Percent	Copper Percent	Chromium Percent	Iron Percent	Molybdenum Percent	Silicon Percent	Manganese Percent	Carbon Percent	Other Percent
Monel	67.0	30.0		1.4		1.0	1.0	0.15	
Nickel	99.4	0.1		0.15		0.05	0.25	0.1	
Inconel	78.5	0.2	14.0	6.5		0.25	0.25	0.08	
18-8 SS (Type 302)	8-10		17-19	Bal.		0.75 max.	2.0 max.	0.20 max.	
18-8 SS (Type 304)	8-10		18-20	Bal.		0.75 max.	2.0 max.	0.08 max.	
18-8 Cb SS (Type 347)	9-12		17-19	Bal.		1.0 max.	2.0 max.	0.10 max.	Cb10xC min.
18-8 Mo SS (Type 316)	10-14		16-18	Bal.	2-3	1.0 max.	2.0 max.	0.10 max.	
14-18% Cr Steel (Type 430)			14-18	Bal.		1.0 max.	1.0 max.	0.12 max.	
10-14% Cr Steel (Type 410)			10-14	Bal.		0.75 max.	0.60 max.	0.15 max.	
Copper		99.9							
Silicon Bronze		96.0				3.0	1.0		
Chemical Lead									Pb 99.9
Hastelloy B	60.0			6.0	32.0	1.0	1.0		
Hastelloy C	51.0		17.0	6.0	19.0	1.0	1.0		W 5.0
Durimet T	22.0	1.0	19.0	Bal.	3.0				
Duriron				Bal.		14.5		0.07 max.	
Tin									Sn 99.75
Zinc									Zn 99.9
Mild Steel				Bal.			0.2-0.5	0.20 max.	
Ni-Resist (Type 1)	13.5-17.5	5.5-7.5	1.75-2.50	Bal.		1.0-2.5	1.0-1.5	3.0 max.	
Cast Iron				Bal.		1.5-2.5	0.5-1.0	3.0-3.5	

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TABLE II

Plant and Laboratory Corrosion Tests in Fruit Juices and Syrups

MATERIAL	Condition	Corrosion Rate, Inch Penetration per Year			
		Inconel	Nickel	Monel	18-8
Tomato Juice	Aerated, Room Temperature	0.0000	0.012	0.003	......
Tomato Juice	Unaerated, Room Temperature	0.0000	0.008	0.0001	......
Tomato Juice	*Fully Aerated, 170° F.	0.0002	0.044	0.015	0.0003
Tomato Juice	*Fully Aerated, 195° F.	0.0002	0.016	0.008	0.0002
Lemon Juice	Aerated, Room Temperature	0.0003	0.020	0.010	......
Lemon Juice	Boiling Under Reflux	......	0.014	0.0006	......
Lemon Juice	Unaerated, Room Temperature	0.0003	0.0005	0.0005	......
Lemon Syrup	Fully Aerated, Room Temperature	0.0000	0.001	......	0.0000
Lemon Syrup, Diluted	Fully Aerated, Room Temperature	0.0002	0.034	......	0.0004
Lime Syrup, Acidified into Citric Acid	Unaerated, Room Temperature	0.0002	0.0001	0.0001	0.0001
Pineapple Juice	Aerated, Room Temperature	0.0000	0.018	0.005	......
Pineapple Juice	Unaerated, Room Temperature	0.0000	0.004	0.0007	......
Pineapple Juice	*Alternate Immersion 132° to 178° F.	0.0004	0.010	0.006	0.0001
Pineapple Juice	*Fully Aerated, 180° F.	0.0007	0.036	0.030	0.0002
Pineapple Juice	*165° to 175° F., 16 to 18 in. Vacuum	<0.0001	0.0045	0.003	0.0003
Grape Juice	Aerated, Room Temperature	0.0000	0.025	0.005	......
Grape Juice	Unaerated, Room Temperature	0.0000	0.006	0.002	......
Grape Juice	*Boiling Under Reflux	0.0004	0.007	0.0003	0.0001
Orange Juice	Boiling Under Reflux	......	0.008	0.0007	......
Orange Syrup	Fully Aerated, Room Temperature	0.0000	0.0007	......	0.0000
Orange Syrup, Diluted	Fully Aerated, Room Temperature	0.0002	0.025	......	0.0004
Apple Juice	Aerated, Room Temperature	<0.0001	0.0004	0.0005	......
Apple Juice	Unaerated, Room Temperature	0.0000	0.0001	0.0001	......
Apple Cider	*Unaerated, Room Temperature	<0.0001	0.001	0.0009	0.0001
Apple Cider	Unaerated, Boiling	<0.0001	0.002	0.0012	<0.0001
Grapefruit Juice	2.7% Citric Acid, Hot	0.0002	0.0002	0.0001	0.0002
Grapefruit Juice	2.7% Citric Acid, Cold	0.0007	0.0006	0.0005	0.0007
85% Grapefruit Juice and 15% Orange Juice	*Aerated, Room Temperature	<0.0001	0.022	0.002	<0.0001
Caramel Color Syrups	*Unaerated, 212° F.	0.0014	0.0015	0.0011	<0.0001†

* Indicates field tests.
† Specimens pitted to a max. depth of .001" on surface and .011" in crevice formed by bakelite and metal surface.

ucts. However, in some applications where the corrosive conditions are especially severe due to a combination of high temperature and strong aeration, Inconel and 18-8 stainless steel prove to be the better materials. Furthermore, when requirements are such that virtually complete freedom from tarnishing of equipment is desirable, Inconel and 18-8 stainless steel are preferred. Generally, tarnishing neither injures the product nor materially decreases the life of the metal, but it may be objectionable on the basis of appearance when the fabricated apparatus is installed where it may be viewed by the public. In spite of occasionally higher rates of corrosion and susceptibility to tarnishing, pure nickel is more widely used than any of the other materials for steam jacketed cooking kettles where economic advantage is derived from its high rate of heat transfer.

Pectin

Pectin is a complex carbohydrate present in certain fruits and its extraction and handling present certain corrosion problems with the more common materials of construction due to the addition of hydrochloric or sulfurous acid during processing. It will be noted from the field test data given in Table III that the greater amount of corrosion occurred in the case of Test 5, where the specimens were exposed to the pectin liquor acidified with hydrochloric acid during evaporation.

TABLE III

Plant Corrosion Tests in the Processing of Fruit Pectin

TEST 1—In degassing tank containing thin pectin liquor at a pH of 2.7 plus 0.2% malic acid and 0.065% SO₂. Average temperature 120° F. Duration of test 30 days. Some aeration and agitation.

TEST 2—In carbon treating tank containing thin pectin liquor at a pH of 3.8 plus 0.26% malic acid and 0.3% carbon. Temperature 95°-150° F. Duration of test 4 days during which 6 treatments were carried out each requiring 15 hours. Agitated constantly with air.

TEST 3—In collecting tank containing thin pectin liquor at a pH of 3.8 plus 0.26% malic acid. Average temperature 135° F. Duration of test 3 days during which 6 batches were collected each requiring 11 hours. No aeration and slight agitation.

TEST 4—In storage tank containing thin pectin liquor at a pH of 2.95 plus 0.20% malic acid and 0.05% free SO₂. Average temperature 80° F. Duration of test 26 days during which tank was drained every 24 hours and fresh liquor added. No aeration but some agitation due to emptying and filling tank.

TEST 5—In evaporator handling pectin liquor acidified with HCl to a pH of from 2.4 to 2.1. Temperature 105° F. and 140° F. under vacuum of 28″ Hg. The evaporation was completed in two stages—the first at 105° F. for 9 hours and the second at 140° F. for 8 hours. Duration of test 52 hours including the 17 hour boiling period. No aeration but agitation due to ebullition.

TEST 6—In storage tank containing concentrated pectin liquor at a pH of 3.30 plus 1% malic acid and traces of sulfites. Average temperature 100° F. Duration of test 27 days. No aeration but slight agitation due to dropping of liquor from the evaporator to the storage tank.

MATERIAL	CORROSION RATE, INCH PENETRATION PER YEAR					
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Monel	0.006	0.0013	0.0009	<0.0001	0.0011	0.0006
Nickel	0.023	0.0035	0.0015	0.0039[1]	....	0.0012
Inconel	0.0001	<0.0001	0.0001	<0.0001	0.0003	<0.0001
18-8 SS (Type 302)	0.0001	<0.0001	0.0001	<0.0001	....	<0.0001
18-8 SS (Type 304)	<0.0001	<0.0001	0.0001	<0.0001	0.0006	<0.0001
18-8 Mo SS (Type 316)	<0.0001	<0.0001	0.0001	<0.0001	0.0005	<0.0001
18-8 Cb SS (Type 347)	0.0002	....	....	<0.0001	0.0004	<0.0001
Copper	0.009	0.0018	0.0012	0.0001	....	0.0018
Silicon Bronze	0.009	0.0026	0.0014	0.0001	....	0.0023

[1]Local attack in the form of pitting to a maximum depth of 0.007 in.

These data do not show any significant superiority of Inconel over the 18-8 types of stainless steel but experience has indicated the former to be the preferred alloy for pectin evaporators. The austenitic stainless steels are known to have a susceptibility toward local attack in the form of pitting in contact with hot, dilute solutions of hydrochloric acid and, for this reason, rather than any incidence of pitting in the relatively short corrosion tests, they are not considered as reliable for the application in question. The use of Monel in this service has been limited by the desire to exclude possible sources of copper contamination even though it possesses a usefully low corrosion rate.

There do not seem to be any particular corrosion difficulties in handling the pectin liquor during degassing, collecting and storage since most of the materials exhibited very low rates of attack. However, in the treating tank where carbon is used for clarification there is a good chance for galvanic corrosion to take place between carbon particles and the metal wall to which they may adhere. This effect has been observed by the author in other similar services where carbon was employed for purification, but in the present case no such phenomenon was noted, probably due to the relatively short duration of test.

Glutamic Acid and Monosodium Glutamate

Glutamic acid is one of the amino acids generally obtained from the hydrolysis of protein-containing

TABLE IV

Plant Corrosion Tests in the Processing of Glutamic Acid and Mono-Sodium Glutamate

TEST 1—In flash chamber of evaporator concentrating crude glutamic acid at a pH of 5.6 from 1.25 specific gravity to 1.33 specific gravity. Average temperature 158° F. No aeration but considerable vapor velocity entering at rate of 720 fpm. Duration of test 36 days.

TEST 2—In a crystallizer handling glutamic acid in a saturated solution of sodium chloride at a pH of 3.2. Average temperature 77° F. Duration of test 28 days. Continuously aerated and agitated by air.

TEST 3—In a crystallizer handling mono-sodium glutamate in a saturated solution of sodium chloride at a pH of 5.0–6.4. Average temperature 86° F. Duration of test 28 days. Continuously aerated and agitated by air.

MATERIAL	CORROSION RATE, INCH PENETRATION PER YEAR		
	Test 1	Test 2	Test 3
Monel	0.0036	0.0026	0.0015
Nickel	0.0064	0.0033	0.0017
Inconel	<0.0001	0.0034	<0.0001
18-8 SS (Type 302)	0.0001[3]	0.0018[1]	0.0002[2]
18-8 SS (Type 304)	0.0002[4]	0.0021[1]	0.0014[4]
18-8 Mo SS (Type 316)	<0.0001	0.0011	<0.0001[2]
13% Cr Steel (Type 410)	0.0073[5]	0.0032[6]	0.0007[2]
Hastelloy B		0.0019	0.0007
Mild Steel	0.022	0.007	0.011
Ni-Resist	0.008	0.004	0.003
Cast Iron	0.017	0.006	0.020

[1] Specimens perforated during test. Original thickness 0.031 in.
[2] Local attack in the form of pitting to a max. depth of 0.004 in.
[3] Local attack in the form of pitting to a max. depth of 0.002 in.
[4] Local attack in the form of pitting to a max. depth of 0.007 in.
[5] Local attack in the form of pitting to a max. depth of 0.015 in.
[6] Local attack in the form of pitting to a max. depth of 0.012 in.

materials such as Steffens Filtrate, occurring in the process of making sucrose from sugar beets, and wheat gluten. It is used along with other amino acids principally as a source of food for quickly rehabilitating undernourished people and for the production of monosodium glutamate which is employed as a condiment in the flavoring of meats and other foodstuffs.

The plant test data shown in Table IV are representative of the corrosive conditions encountered in various steps in the production of these chemical compounds. The figures indicate that in these services a number of the materials tested were subject to local attack in the form of pitting and in several cases to the extent of perforation. Both Monel and Inconel exhibit satisfactorily low corrosion rates in the evaporator and crystallizers and these data are in harmony with and have been confirmed by practical exeprience with the use of these materials for such equipment.

Gelatin

Mineral acids, principally hydrochloric acid, are used in the extraction of gelatin from animal tissues (bones, ligaments and skin). The results of a number of plant corrosion tests in the production and storage of gelatin involving the presence of hydrochloric acid are given in Table V. The figures indicate that Monel, nickel and Inconel, as well as the austenitic stainless steels and the straight chromium varieties, are highly resistant to corrosion, but because of the susceptibility of the latter materials to local attack, they

TABLE V
Plant Corrosion Tests in the Production of Gelatin

TEST 1—In the evaporation of gelatin solution at a pH of 3.8 to 6.8 from 4% to 20% solids. It was reported that traces of sulfuric, hydrochloric and nitric acids as well as sulfur dioxide were present in the gelatin solution. Temperature 172° F. Duration of test 27 days. No aeration but agitation due to ebullition.

TEST 2—In the storage of gelatin solution with hydrogen peroxide under alternate acid and alkaline conditions. Temperature not reported but presumed to be atmospheric. Duration of test 30 days. No aeration or agitation.

TEST 3—In 15-20% gelatin solution during extraction from animal hides by cooking in dilute hydrochloric acid. Average temperature 180° F. Duration of test 24 days. Slight aeration and mild agitation.

TEST 4—In 0-10% gelatin solution during extraction from pig skins by cooking in dilute hydrochloric acid. pH of gelatin solution 4.0. Temperature varied from 115°-212° F. Duration of test 43 days. Slight aeration and agitation.

TEST 5—In 0-10% gelatin solution during extraction from ossein (animal bone marrow) by cooking in dilute hydrochloric acid. Temperature varied from 135° 212° F. Duration of test 43 days. Slight aeration and agitation.

MATERIAL	CORROSION RATE, INCH PENETRATION PER YEAR				
	Test 1	Test 2	Test 3	Test 4	Test 5
Monel	.....	0.0004	0.0044	.....	.....
Nickel	0.0019	0.0007	0.0042	0.0008	0.0017
Inconel	<0.0001	<0.0001	<0.0001[2]	<0.0001	<0.0001
18-8 SS (Type 302)	<0.0001	0.0002	.....	<0.0001	<0.0001
18-8 SS (Type 304)	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
18-8 Mo SS (Type 316)	<0.0001	<0.0001	.....	.....	.....
17% Cr Steel (Type 430)	0.0010[1]	.....	0.0003[3]	<0.0001	<0.0001
13% Cr Steel (Type 410)	.....	.....	.....	0.0004[4]	0.0008[5]

[1] Local attack in the form of pitting to a max. depth of 0.006 in.
[2] Local attack in the form of pitting to a max. depth of 0.003 in. on one specimen and 0.014 in. on other specimen.
[3] Local attack in the form of pitting to a max. depth of 0.004 in.
[4] Local attack in the form of pitting to a max. depth of 0.005 in.
[5] Local attack in the form of pitting to a max. depth of 0.008 in.

are not generally used. On the other hand, since Monel and nickel are not subject to this type of attack, they are used rather extensively for such equipment as evaporators, drying nets, heating coils, kettles, storage tanks, etc. Inconel has been found to provide exceptional resistance to the destructive corrosive and mechanical forces encountered by gelatin drying nets and has become the preferred material for this service.

Mayonnaise and Salad Dressing

From the data presented in Test 1 and 2 in Table VI, it will be seen that Inconel, 18-8 stainless steel and the 17

TABLE VI
Laboratory and Plant Corrosion Tests in Mayonnaise and other Salad Dressings

TEST 1—In mayonnaise beater bowl containing mixed spices, sugar, salt, eggs, salad oil and vinegar. Temperature atmospheric. Duration of test 5 days. Mixture was both aerated and agitated.

TEST 2—In storage of the above mayonnaise. Temperature atmospheric. Duration of test 21 days. No aeration or agitation.

TEST 3—In boiling solution of 1% by weight acetic acid (as vinegar) and 5% salt used in the preparation of salad dressing. Temperature boiling. Duration of test 100 hours and 20 days. No aeration but agitation due to ebullition.

TEST 4—In the above salad dressing after cooking. Temperature atmospheric. Duration of test 21 days. No aeration or agitation.

MATERIAL	CORROSION RATE INCH PENETRATION PER YEAR			
	Test 1	Test 2	Test 3	Test 4
Monel	0.006	<0.0001	0.029	<0.0001
Nickel	0.017	<0.0001	0.025	<0.0001
Inconel	.....	<0.0001	0.020	<0.0001
18-8 SS (Type 302)	.....	<0.0001	0.002[1]	<0.0001
18-8 SS (Type 304)	0.0003	<0.0001	0.002[1]	<0.0001
18-8 Mo SS (Type 316)	.....	.....	.....	.....
17% Cr Steel (Type 430)	0.0003	.....	.....	.....

[1] Local rusting with several deep pits.

TABLE VII

Laboratory and Plant Corrosion Tests In Coffee Brew and Extract

TEST 1—In beverage coffee made by circulating 2 gallons of water through one pound of ground well-known brand coffee contained in a clean muslin bag. Temperature 195°–200° F. Duration of test 2 hours. No aeration but agitation due to flow of water.

TEST 2—In Coffee extract contained in a stone crock. Temperature 40° F. Duration of test 30 days. No aeration or agitation.

MATERIAL	Corrosion Rate Inch Penetration per Year	
	Test 1	Test 2
Monel	0.0007	0.0001
Nickel	0.0027	0.0003
Inconel	-0.0015	<0.0001
18-8 SS (Type 304)	0.0010	<0.0001
Tin	0.0060	....

percent chromium steel are the most suitable materials for whips and beater bowls in contact with mayonnaise at atmospheric temperature, because all are immune to significant attack and, as found from careful examination, free from tarnish. Nickel and Monel are less suitable chiefly because of their tendency to tarnish, which may or may not be considered a serious objection. The manufacture of cooked salad dressing requires the use of materials for the cooking kettles that can withstand the effects of prolonged contact with boiling solutions of vinegar and salt, and it is evident from Test 3 that such mixtures are very corrosive. None of the materials tested showed up satisfactorily, since Monel, nickel and Inconel exhibit rather high rates of corrosion and the 18-8 stainless steels, while they possess low rates of attack, as measured by weight loss, were subject to rather severe local attack.

Experience has demonstrated, however, that 18-8 molybdenum stainless steel (Type 316) represents the best choice of material for han-dling such mixtures. Even so, this stainless steel shows some tendency towards pitting which can be kept to a minimum by having the surface of the steel as highly polished as possible and by cleaning the surfaces to remove any salty solids after each use.

Another "trick" that has been used with good results in the manufacture of salad dressing is to delay the addition of salt to the product as long as possible, that is, to add all the other ingredients first and then when the product is just about finished, add the salt. This, of course, reduces the time during which the material must resist attack by the acetic acid-salt mixture.

Coffee Brew and Extract

The results of Test 1, tabulated in Table VII, represent the average of seven different determinations of the weight loss sustained by the samples of each metal. It is evident from these data that beverage coffee has only a very slight action on all the metals and alloys included in the test. Similarly, the corrosive effect of coffee extract, as shown by the

TABLE VIII

Plant Corrosion Test in the Production of Concentrated Vanilla Extract

CONDITIONS OF TEST—Specimens exposed to alcoholic solvent and vanilla beans during steeping and percolation. Average temperature 68° F. Duration of test 162 days. Aeration none but some agitation due to periodic circulation.

MATERIAL	Corrosion Rate Inch Penetration Per Year
Monel	0.0007
Nickel	0.0008
Inconel	<0.0001
18-8 SS (Type 302)	<0.0001
18-8 SS (Type 304)	<0.0001

TABLE IX

Laboratory Corrosion Tests in Carbonated Water and Beverages

TEST 1—In carbonated water under CO_2 pressure of 50 pounds gauge. Temperature atmospheric. Duration of test 5 days. No aeration or agitation.

TEST 2—In carbonated lime flavored water under CO_2 pressure of 40 pounds gauge. Temperature atmospheric. Duration of test 5 days. No aeration or agitation.

TEST 3—In carbonated ginger ale containing 0.03% citric acid. Temperature atmospheric. Duration of test 32 days. No aeration or agitation.

MATERIAL	Corrosion Rate Inch Penetration per Year		
	Test 1	Test 2	Test 3
Monel	0.0001	0.0002	<0.0001
Nickel	0.0001	0.0002	<0.0001
Inconel	0.0001	0.0001	....
18-8 SS (Type 302)	<0.0001	0.0001	....
18-8 SS (Type 304)	<0.0001	0.0001	....
Block Tin	0.0001	0.0006	0.0006

results of Test 2, is also negligible in nature. The wide use and satisfactory performance of Monel and 18-8 stainless for coffee-making equipment bear out the results of these findings.

Vanilla Extract

A field test was made during the maceration and percolation of vanilla beans in an alcoholic solvent in the production of concentrated vanilla extract and the results are given in Table VIII. The service conditions did not prove to be at all severe and all the materials tested gave negligibly low corrosion rates. Incidentally, as a result of this test, the user selected Inconel for his processing equipment not only because of its very low corrosion rate, but also on account of the fact that it retained its original appearance to a much greater extent than the other materials tested.

Carbonated Water and Beverages

Carbonated water and beverages, while not especially corrosive, as

TABLE X

Plant Corrosion Test in the Vacuum Evaporation of Meat Juice Extract

CONDITIONS OF TEST—Animal tissue containing 0.5% to 40% organic solids and inorganic salts of sodium and potassium chlorides as well as about 3% phosphates. Hydrochloric acid used for acidification to a pH of 4.0–5.0. Temperature varied from 120°–180° F. Duration of test 60 days during which evaporator operated only 129.5 hours. No aeration but some agitation due to evaporation.

MATERIAL	Corrosion Rate Inch Penetration per Year	
	Based on 60 Days Total Exposure	Based on 129.5 Hours Actual Evaporating Time
Monel	0.0003	0.0033
Nickel	0.0010	0.011
Inconel	<0.0001	0.0002
18-8 SS (Type 302)	<0.0001	0.0002
18-8 SS (Type 304)	<0.0001	0.0002
Mild Steel	0.0055	0.061
Ni-Resist	0.0004	0.0045
Cast Iron	0.0045	0.050

shown by the test results in Table IX, are highly sensitive to off-flavor because of the pickup of small amounts of certain metallic salts, notably copper and iron. In the past, block tin was used almost exclusively in this service, but in recent years, because of the shortage of this metal, more and more items of equipment, such as carbonators, dispensing machines and lines, have been fabricated of nickel, Inconel and austenitic stainless steel. These materials have performed very satisfactorily from the corrosion resistance standpoint and, like tin, do not contribute any detectable metallic contamination to the beverages. Monel has found relatively limited application because of its copper content. A new type of nickel tubing has been developed which is essentially carbon free and possesses a very high degree of ductility and ease of coiling. This property has led to its wide use as a replacement for tin for cooling coils and leader lines from carbonators to dispensers.

The preferred materials for handling the carbonated fruit syrups in addition to tin are Inconel and the 18-8 stainless steels.

Meat Juice Extract

The production of meat juice extract by evaporation does not seem to be a significantly corrosive service as shown by the rather low rates of attack suffered by the materials tested in Table X. Monel and nickel are generally the preferred materials for use in contact with solutions containing small amounts of hydrochloric acid which are either added purposely to processing liquors, or are formed by hydrolysis in the reaction. The stainless steels are generally considered less reliable because of susceptibility to local attack in the presence of hydrochloric acid.

Vinegar

Results of plant corrosion tests in the storage of vinegar, and in its handling during pasteurization are given in Table XI. The data indicate that the materials studied under the particular conditions of the test were all highly resistant to corrosion. An increase in the corrosion rates of Monel and nickel may be observed in the case of the test at 140° F., but they are of a sufficiently low order to make the use of these materials practical. Inconel and the austenitic stainless steels were in no way affected by the change in temperature and these alloys have proved to be highly useful for handling vinegar solutions of all concentrations up to boiling, both aerated and unaerated. Some materials like Monel, nickel and copper are strongly affected by aeration in the

TABLE XI

Plant Corrosion Tests in the Handling of Vinegars

TEST 1—In vinegar storage tank containing concentrations up to 100 grain. One set of specimens was exposed near bottom of tank and another set near liquid level. Temperature atmospheric. Duration of test 240 days. No aeration at bottom of tank but alternate exposure to air at liquid level when tank was emptied and filled. No agitation except on emptying and filling tank.

TEST 2—In vinegar pasteurizer, at times containing both grain and cider vinegar. Temperature 140° F. Duration of test 220 days. No aeration or agitation.

MATERIAL	Corrosion Rate Inch Penetration per Year		
	Test 1		Test 2
	Near Bottom of Tank	Near Liquid Level	
Monel	0.0003	0.0003	0.0014
Nickel	0.0003	0.0005	0.0019
Inconel	<0.0001	<0.0001	<0.0001
18-8 SS (Type 302)	<0.0001	<0.0001	<0.0001
18-8 SS (Type 304)	<0.0001	<0.0001	<0.0001
Tin	0.0022	0.0004	......
Copper	......	......	0.0036

presence of such solutions and under the circumstances they generally do not prove satisfactory where more than slight corrosion cannot be tolerated.

Pickling and Canning Brines

Pickling and canning brines are generally made up with small amounts of organic acids, such as acetic or lactic, plus salt and/or sugar. Table XII gives the results of eight plant corrosion tests in pickling brines for herring, olives, cucumbers, onions, sauerkraut and sausage and in canning brines for corn and peas. No significant amount of corrosion occurred on the majority of the materials tested, but a few of them showed pitting corrosion or incipient local attack as evidenced by the formation of rust spots. Copper, tin, mild steel and zinc were not generally satisfactory and, in fact, exhibited a relatively low order of corrosion resistance. Monel, nickel

TABLE XII
Plant Corrosion Tests in Pickling and Canning Brines

TEST 1—In tank containing herring and pickling brine consisting of 12% sucrose, 2% acetic acid, plus small amount of salt from herring and balance water. Temperature 40° F. to atmospheric. Duration of test 116 days. No aeration or agitation.

TEST 2—In olive brine tank containing sodium chloride and small amount of lactic acid. Temperature cold. Duration of test 220 days. No aeration or agitation.

TEST 3—In cucumber pickle preheater containing cider and grain vinegar plus sugar. Temperature 140° F. Duration of test 85 days. No aeration or agitation.

TEST 4—In kettle used in the preparation of onion pickling brine consisting of 3% sodium chloride, 2% acetic acid and 35% sugar. Temperature boiling. Duration of test 2 hours. No aeration but agitation due to ebullition.

TEST 5—In vessell containing sausage casing brine consisting of sodium chloride plus sulfate and sulfur compounds. Temperature atmospheric. Duration of test 4 days. No aeration or agitation.

TEST 6—In sauerkraut brine containing vinegar and sodium chloride. Temperature atmospheric. Duration of test 120 days. No aeration or agitation.

TEST 7—In pea brine tank containing a mixture of 10 lbs. salt and 25 lbs. sugar in 100 gallons of water. Temperature boiling. Duration of test—10 individual tests were made lasting from 8 to 10 hours each, and the data are based on an average of the maximum and minimum rates observed. No aeration or agitation.

TEST 8—In corn brine tank containing a mixture of 20 lbs. salt and 100 lbs. sugar in 100 gallons of water. Temperature boiling. Duration of test—5 individual tests were made lasting from 8 to 10 hours each and the data are based on an average of the maximum and minimum rates observed. No aeration or agitation.

	CORROSION RATE, INCH PENETRATION PER YEAR							
MATERIAL	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Monel	0.0001	0.0019	....	0.0008	0.0008	0.0001	0.0010	0.0018
Nickel	0.0001	0.0023	0.0035	0.0031	0.0007	0.0005	0.0011	0.0010
Inconel	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001[1]	....	....
18-8 SS (Type 302)	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	....	....
18-8 SS (Type 304)	<0.0001	<0.0001	<0.0001	<0.0001			0.0006[2]	0.0003[2]
18-8 Mo SS (Type 316)	<0.0001							
Copper		0.0033		0.015			0.024	0.027
Tin				0.030			0.005	0.0056
Mild Steel	0.0004			0.11			....	....
Zinc							0.030	0.040

[1] Local attack in the form of pitting to a max. depth of 0.008 in.
[2] Specimens showed small rust spots.

and Inconel have all proved by practical application to be well suited for handling these various brines and they are usually preferred along with Type 316 stainless steel for equipment used in this service. Types 302 and 304 stainless steel have, on occasion, shown a definite susceptibility to local attack resulting in premature failure in contact with these brines, and must be considered of questionable suitability for this sort of service.

Manufacture and Washing of Sausage Casing

The results of two corrosion tests made in a glycerinizing tank used in the manufacture of cellulose sausage casing and in the washing of sausage casing after extrusion are given in Table XIII. The materials

TABLE XIII
Plant Corrosion Tests in the Manufacture and Washing of Sausage Casing

TEST 1—In glycerinizing tank containing 10% glycerine solution, adjusted to pH 6.0 with acetic acid, and purified cellulose sausage casing strip. Average temperature 140° F. Duration of test 61 days. Slight aeration and agitation.

TEST 2—In washing of sausage casings after extrusion. Wash water contained 0.4% sulfuric acid and 1.25% sodium sulfate. Temperature 104° F. Duration of test 60 days. Slight aeration and agitation due to continuous circulation of the water.

	Corrosion Rate, Inch Penetration per Year	
MATERIAL	Test 1	Test 2
Monel	0.0049[1]	0.0067
Nickel	0.0058[2]	0.0071
Inconel	0.0041[3]	0.0048[3]
Type 304 SS	0.0004[3]	0.0037
Type 316 SS	<0.0001	

[1] Local attack in the form of pitting to a maximum depth of 0.003 in.
[2] Local attack in the form of pitting to a maximum depth of 0.015 in.
[3] Specimens perforated during test. Original thickness 0.031 in.

TABLE XIV

Plant Corrosion Tests in the Production and Handling of Oleomargerine

TEST 1—In boil down tank in the production of oleomargerine from animal fatty acids. Eleven batches of oleomargerine were boiled from 10 to 30 minutes each and left to settle over night. The acid water used was about 0.75% strength. Temperature varied from atmospheric to boiling. Duration of test 38 days, during which 160,000 pounds of stock were worked. No seration but agitation due to boiling.

TEST 2—In the transportation of oleomargerine made from a mixture of beef fat and buttermilk with a calculated acid content of 0.35%. Temperature atmospheric. Duration of test 1 day. No aeration or agitation.

MATERIAL	Corrosion Rate Inch Penetration per Year	
	Test 1	Test 2
Monel	0.0012	0.0019
Nickel	0.0012	0.0002
Inconel	0.0009	
18-8 SS (Type 302)	0.0001	
18-8 SS (Type 304)	0.0001	
Copper	0.0040	
Ni-Resist	0.0042	
Cast Iron	0.0020	

investigated in Test 1 exhibited a rather strong tendency towards localized attack with the exception of Type 316 stainless steel. This material remained free of pitting and proved to have a negligibly low overall corrosion rate as measured by weight loss. Test 2 was much less severe insofar as pitting was concerned and indicated the suitability of Monel, nickel and Type 304 stainless steel for this type of service. Under this exposure condition Inconel was again subject to local attack and, while Type 316 stainless steel was not included in this study, it would, undoubtedly, have performed at least as well as the Type 304 stainless steel.

Oleomargarine

The data given in Table XIV were obtained from plant corrosion tests in the production and handling of oleomargerine. It is evident that in the boil-down tank only cast iron is subject to rather high rates of at-

TABLE XV

Plant Corrosion Test in the Production of Tartaric Acid

CONTITIONS OF TEST—In vacuum pan evaporator concentrating pure tartaric acid to 57%. Temperature 130° F. Duration of test 20 days during which equipment operated only 240 hours. No aeration but agitation due to ebullition.

MATERIAL	Corrosion Rate Inch Penetration Per Year
Monel	0.005
Nickel	0.008
Inconel	0.002¹
Copper	0.015
Chemical Lead	0.060

¹ Local attack in the form of pitting to a maximum depth of 0.001 in.

tack, while the other materials tested are adequately resistant to corrosion. Copper or copper salts are known to have a strong influence in developing rancidity in fatty acids and for this reason this material is generally not considered satisfactory for use in such service. While Monel contains about 30 percent copper, its corrosion rate is usually of such a low enough order that it has been employed successfully for handling such acids.

Unfortunately, in connection with Test 2, Monel and nickel were the only materials investigated and, under the conditions, they demon-

TABLE XVI

Plant Corrosion Tests in Hot Processing of Maraschino Cherries

CONDITIONS OF TEST—In syruping tank with cherry liquor containing 600–1000 ppm of SO₂ at start. Temperature 132°–160° F. Duration of test 183 days during which 25 batches were processed each requiring about 4 days. Balance of time specimens were exposed to air at room temperature. No aeration or agitation reported.

MATERIAL	Corrosion Rate Inch Penetration Per Year
Monel	0.0003
Nickel	0.0025
Inconel	0.0001
18-8 SS (Type 302)	<0.0001
18-8 SS (Type 304)	<0.0001
18-8 Mo SS (Type 316)	0.0001

TABLE XVII

Plant Corrosion Tests in the Preparation of Baker's Yeast

CONDITIONS OF TEST—In liquid and vapor phases of process tank handling yeast cultures. Temperature atmospheric. Duration of test 168 days. Aeration good with practically no agitation.

MATERIAL	Corrosion Rate, Inch Penetration per Year	
	In Liquid	In Vapor
Monel	0.0011[1]	0.0005[4]
Nickel	0.0054[2]	0.0011[6]
Inconel	<0.0001[3]	<0.0001[7]
Copper	0.0022[4]	0.0038[7]
Tin	0.0002[1]	0.0001[1]
Mild Steel	0.0068[5]	0.0064[5]

[1] Local attack in the form of pitting to a maximum depth of 0.005 in.
[2] Local attack in the form of pitting to a maximum depth of 0.008 in.
[3] Local attack in the form of pitting to a maximum depth of 0.006 in.
[4] Local attack in the form of pitting to a maximum depth of 0.004 in.
[5] Local attack in the form of pitting too severe to permit accurate measurement.
[6] Local attack in the form of pitting to a maximum depth of 0.003 in.
[7] Local attack in the form of pitting to a maximum depth of 0.002 in.

strated usefully low rates of corrosion, with nickel showing a superiority of better than 9 to 1.

Tartaric Acid

In the production of cream of tartar, wine lees are treated with sulfuric acid and other chemicals to release the tartaric acid, which is subsequently concentrated by evaporation and crystallization. The results of a plant corrosion test in a vacuum pan evaporator concentrating pure tartaric acid to 57 percent are given in Table XV. It will be noted that both copper and lead suffered relatively high rates of corrosion as compared to Monel, nickel and Inconel. Prior to the running of this test, both copper and lead were the materials most generally used for tartaric acid evaporators and they did not prove to be altogether satisfactory. On the basis of

TABLE XVIII

Plant Corrosion Test in Air-Chlorine Mixture Used in Flour Bleaching

CONDITIONS OF TEST—Air-chlorine mixture consisted of 300 cu. ft. of air and 50 ozs. of chlorine per hour. Average temperature 80°F. Duration of test 82 days during which the specimens were exposed to the corrosive media only 128 hours. Good aeration and agitation.

MATERIAL	Corrosion Rate Inch Penetration Per Year
Monel	0.012
Nickel	0.003
Inconel	0.011
18-8 SS (Type 304)	0.044
18-8 Mo SS (Type 316)	0.022
Chemical Lead	0.001
Hastelloy C	0.0001

the superior performance shown by Monel in the test, it was specified for some evaporating equipment and practical experience has demonstrated that it was a wise choice of material. Monel is giving a much longer service life than ever obtained with either copper or lead and currently it is being user rather widely for various types of equipment such as tanks, tank linings, utensils, filter cloth, hoppers, chutes, etc. in cream of tartar manufacturing plants.

Maraschino Cherries

The data given in Table XVI were obtained in a syruping tank during the hot processing of Maraschino cherries in the presence of sulfur dioxide. Corrosion in this application does not appear to be a factor insofar as the materials tested are concerned, since all of them showed low rates of attack. However, it should be pointed out that sulfur dioxide, even in dilute solutions, often produces rapid corrosion on many metals and, under the circumstances, it might be presumed that the syrup or cherry liquor used in the hot processing during the test

TABLE XIX

Laboratory and Plant Corrosion Tests in the Handling of Condiments

TEST 1—In steam autoclave during processing of Worcestershire Sauce. Temperature 266°–275° F. Duration of test 20 hours. No aeration or agitation.

TEST 2—In steam autoclave during processing of India Thick Sauce. Temperature 266°–275° F. Duration of test 21 hours. No aeration or agitation.

TEST 3—In mustard powder after grinding. Temperature 70° F. Duration of test 22 hours. No aeration or agitation.

TEST 4—In chili sauce containing red peppers and seasoning (acetic acid, etc.). Unaerated at boiling temperature for 8 hours and aerated at room temperature for 23 hours. No Agitation.

| MATERIAL | CORROSION RATE, INCH PENETRATION PER YEAR | | | | |
| | Test 1 | Test 2 | Test 3 | Test 4 | |
				Boiling	Room Temp.
Monel	0.0033	0.006	0.0002	0.009	0.004
Nickel	0.010	0.011	0.0027	....	....
Inconel	....	....	0.0001	....	....
18-8 SS	0.0003	0.001	<0.0001	....	....
18-8 Mo SS	....	....	0.0001	....	....

had an inhibiting effect on corrosion of the materials investigated.

Baker's Yeast

In the preparation of baker's yeast, as shown by the data given in Table XVII, all of the materials tested suffered pitting attack to some extent, although the overall corrosion rates as measured by weight loss were reasonably low. Mild steel, of course, was more seriously affected and would not be considered worthy of use in this service. However, some of the other materials, notably Inconel and copper, would possibly prove suitable in spite of the localized attack when the relatively long test period of 168 days is taken into account. The stainless steels were not included in this test, but the Type 316 alloy should be considered as probably suitable for this service.

TABLE XX

Plant Corrosion Tests in the Handling of Corn Syrup and Black Strap Molasses

TEST 1—In vapor and liquid phases of tank car during transportation of corn syrup. Temperature 80°–110° F. Duration of test 85 days in vapor and 104 days in liquid. Little aeration and some agitation due to movement of tank car.

TEST 2—In vapor and liquid phases of corn syrup mixing tank. Temperature 170° F. Duration of test 114 days. Slight aeration and constant agitation.

TEST 3—In vapor and liquid phases of black strap molasses mixing tank. Temperature 225° F. Duration of test 44 days. Slight aeration and constant agitation.

| MATERIAL | CORROSION RATE, INCH PENETRATION PER YEAR | | | | | |
| | Test 1 | | Test 2 | | Test 3 | |
	In Vapor	In Liquid	In Vapor	In Liquid	In Vapor	In Liquid
Monel	0.0002	<0.0001	<0.0001	<0.0001	0.0013	0.0006
Nickel	0.0006	<0.0001	0.0001	<0.0001	0.0011	0.0004
Inconel	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
18-8 SS (Type 302)	....	....	....	....	<0.0001	<0.0001
18-8 SS (Type 304)	....	....	....	....	<0.0001	<0.0001
Copper	....	....	....	....	0.0038	0.0017
Mild Steel	0.0006	0.0007	0.0008	0.0010	0.0069	0.0060
Ni-Resist	0.0012	0.0002	0.0004	0.0002	....	....
Cast Iron	0.0046	0.0010	0.0018	0.0011	....	....

Flour Bleaching

In the bleaching of flour air-chlorine mixtures are used which together with small amounts of moisture usually present in the flour and the air creates a rather somewhat corrosive condition. The test results given in Table XVIII were obtained in such a process and indicate that Hastelloy C, lead and nickel are highly resistant to corrosion. Monel and Inconel were attacked at somewhat higher rates, with the austenitic stainless steels giving the poorest performance of the various materials tested.

Condiments

Some laboratory and plant corrosion test data obtained in the processing or preparation of Worcestershire Sauce, India Thick Sauce, mustard powder and chili sauce are given in Table XIX. These figures indicate the general suitability of Monel, nickel, Inconel and the austentic stainless steels for use in handling these various condiments. However, caution must be exercised to avoid having particles of the salty wet solids remain in prolonged contact with the alloy surfaces, since pitting may be expected under such circumstances.

Corn Syrup and Black Strap Molasses

A series of corrosion tests were made in the liquid and vapor phases of corn syrup during transportation in a tank car and during mixing in a tank, as well as in the liquid and vapor phases of black strap molasses during mixing. The results of these several investigations are shown in Table XX. The data indicate that the conditions are not significantly corrosive even to mild steel and cast iron, which could probably be used to advantage if contamination by rusting were not a factor.

References

1. Drinker, Fairhall, Ray and Drinker, "The Hygienic Significance of Nickel," The Journal of Industrial Hygiene, **VI**, No. 8, 307-356, (1924), Dec.
2. Titus, Elkins, Finn, Fairhall and Drinker, "Contamination of Food Cooked or Stored in Contact with Nickel-Chromium-Iron Alloys," The Journal of Industrial Hygiene, **XII**, No. 8, 306-313, (1930), October.
3. W. E. Pratt, "Does the Nickel Dissolved from the Container During Pasteurization Catalyze the Destruction of the Vitamins of Milk," Journal of Nutrition, **3**, No. 2, 141-55, (1930).
4. Ziels and Drinker, "Catalytic Effect of Metals and Light on Fats and Oils, Oil and Soap Journal of the American Oil Chemists' Society, **22**, No. 12, 327-330, (1945), Dec.
5. A.S.T.M. Standards, Part I, p 52, 1944.

Alloying Steels for Corrosion Resistance To Gas-Condensate Fluids* —Part 2

(Conclusion)

By C. K. Eilerts,[1] Faye Greene,[2] F. G. Archer,[3]
Betty Hanna[4] and L. M. Burman[5]

Carbon Steels

A METAL resembling the carbon steel used in the manufacture of well tubing was included in the various corrosion tests to provide results against which test data on other steels and alloys could be compared. Commercial, hot-rolled, low-carbon, 16-gage, sheet steel identified in this report as SAE 1005 was used as the reference steel. Although consistent corrosion data were obtained when this steel was exposed in the corrosive mediums, an etching test made on a sectional surface of the steel sheet showed "rims" of oxide-free steel enclosing a core that might be more susceptible to corrosion than the outside layer or rim. With the thought of obtaining a more uniform material than the commercial sheet steel as the corrosion standard, some 16-gage sheets of "killed" steel were obtained and used as standard coupons in some of the tests. In the manufacture of the material identified in this report as killed steel, 3.5 pounds of aluminum per ton of metal had been added to the ladle and molds to deoxidize the steel. The compositions of low-carbon steels tested, including the killed and SAE 1005 steels, are given in Table II.

Using the 7-day test procedure, three or more coupons of killed steel and SAE 1005 steel were exposed in propionic and carbonic acids to determine their relative rates of corrosion. Table III shows the results obtained and indicates the precision of the measurements. There was little difference in the rates of corrosion of the metals, and the precision uncertainty was less than 2 percent for the propionic acid tests and less than 10 percent for the carbonic acid tests. There was no

TABLE II

Carbon Steels, Composition and Physical Properties

MATERIAL IDENTIFICATION	COMPOSITION, PERCENT								
	Cr	Ni	Cu	C	Mn	P	S	Si	Mo
SAE 1005[1]	0.00	0.01	0.06	0.034	0.27	0.01	0.026	0.01	0.01
Killed Steel[2]	0.002	0.006	0.008	0.05	0.30	0.005	0.030	0.006	
Cast HE-3604 L-A[3]				0.38	0.70	0.026	0.025	0.41	
J-55[4]				0.46	1.06	0.025	0.019	0.17	

MATERIAL IDENTIFICATION	PHYSICAL PROPERTIES				
	Heat Treatment	Tensile Strength, Psi.	Yield Point, Psi.	Elongation, Percent in 2 In.	Hardness, Brinell
SAE 1005	As hot rolled				123
Killed Steel	As hot rolled				119
Cast HE-3604 L-A	Tempered	91,500	53,000	22.5	
J-55	Normalized	111,420	73,950	28.5	

[1] From a commercial hot-rolled sheet of low-carbon steels.
[2] Sample furnished by Carnegie-Illinois Steel Corporation.
[3] Sample furnished by Lebanon Steel Foundry.
[4] A material obtained by flattening API grade J-55 tubing and normalizing it at 1550° F.

consistent change in the rates of corrosion measured on the SAE 1005 steel as the 7-day tests were repeated, and the results are interpreted to indicate that the rim on the steel did not affect appreciably the usefulness of SAE 1005 steel as a corrosion standard.

TABLE III

Comparison of the Rates of Corrosion of Standard Coupon Materials SAE 1005 and Killed Steel;

Averages of 28 Measurements Using the 7-Day Test

| Coupon	RATE OF CORROSION, mdd	
	Propionic Acid	Carbonic Acid
SAE 1005		
1	29.0	7.8
2	30.7	10.2
3	29.9	9.3
Average	29.9	9.1
Killed Steel		
1	27.9	10.5
2	29.4	12.1
3	28.5	12.7
4		10.8
Average	28.6	11.5

The carbon steel used by the Metallurgical Subcommittee of the National Association of Corrosion Engineers as a corrosion standard in tests made at seven wells also was tested. The steel, which is identified in Table II as J-55, contained 0.46 percent carbon as compared with 0.034 percent carbon in the SAE 1005 steel and 0.05 percent carbon in the killed steel. This steel was of particular significance because it was made from API grade J-55 tubing.

The rates of corrosion of the carbon steels are reported in Table IV. On the basis of the 7-day test in carbonic acid, the rates of corrosion of the four carbon steels are in the same order as their carbon contents; that is, the more the contained carbon the higher the rate of corrosion. Figure 8 is an assembly of photomicrographs which includes three of the carbon steels, showing the relative areas covered by carbide and ferrite phases. The ratio of the carbide area (black) to the
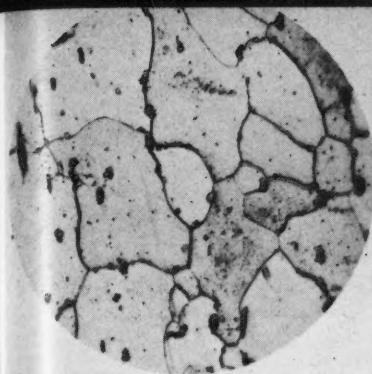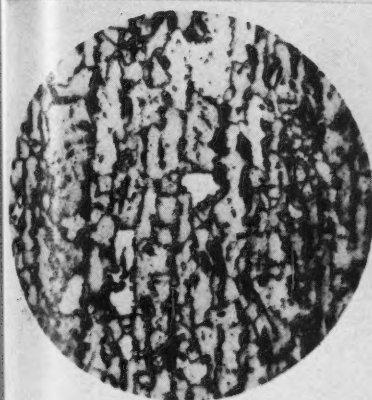
SAE 1005
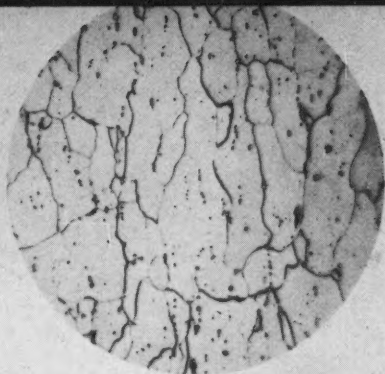
KILLED STEEL

Y-6400

J-55

Figure 8—Transverse microstructures of metals showing the distribution of carbon.

ferrite area (white) is greatest in the J-55 steel containing the highest percentage of carbon. If it be assumed that ferrite areas are anodic with respect to the carbide areas, it is possible to explain the difference in the rates of corrosion of the J-55 and the SAE 1005 and killed steel. The galvanic current flowing through the anodic areas is at the greatest current density and accom-

panies the highest rate of corrosion when the ratio of cathode area to anode area is relatively high as is the case in the J-55 steel.

Exceptions to the theory that low-carbon steels are more resistant to corrosion than high-carbon steels have been cited by Holmberg,[7] who found that a carburized ring gasket containing more than 1.0 percent carbon at the surface in the form of

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peralite and cementite was more resistant to corrosion by gas-condensate fluid than practically carbon-free iron rings. Other examples were discussed by Holmberg, who concluded that the manner in which carbon is distributed in a steel is a factor of considerable importance in attaining corrosion resistance. Manuel[8] investigated the "ringworm" corrosion that affects upset tubing and decided that the spheroidized structure which forms in a short section of the tube near the end in the upsetting operation is less resistant to corrosion than the well-formed pearlitic structure usually found in the middle section of the tube.

Chromium Steels

A series of eight steels containing chromium in amounts varying from 0.99 to 17.9 percent with all other alloying elements substantially constant was used to determine the effect of chromium concentrations on the rate of corrosion of steel. Coupons of killed steel were included in the series to provide a reference material containing only traces of chromium. A steel containing 12.48 percent chromium and 0.47 percent nickel (used commercially in making cast-steel valve bodies and fittings for gas-well Christmas-tree assemblies) also was tested. The compositions of the materials are given in Table V.

Measurements of the rate of corrosion of the chromium steels are given in Table VI. Data obtained by tests in all three of the corrosive mediums showed that the corrosion resistance of steel was not improved unless the steel contained at least 5.00 percent chromium. The corrosion resistance to all mediums, particularly propionic and carbonic acids, was greatly improved by increasing the chromium content from 5.00 to 7.11 and to 9.84 percent. The steels containing more than 12 percent chromium were but little affected by corrosion.

The graphic method used in determining the averages of the data obtained by the 7-day test is illustrated in Figures 9, 10, and 11. The coordinate units of these figures are the same as those of Figures 5 and 6, but different con-

TABLE IV

Carbon Steels, Rates of Corrosion

Material Identification	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Average Rate of Corrosion During Indicated Period of Continuous Exposure, mdd														
		Propionic Acid				Carbonic Acid					Phenol					
		1 dy.	7 dy.	28 dy.	70 dy.	140 dy.	1 dy.	7 dy.	28 dy.	70 dy.	140 dy.	1 dy.	7 dy.	28 dy.	70 dy.	140 dy.
SAE 1005		45	30.	13.0	12.7	21	9.0	9.1	18.4	28.	62	30	4.6	6.1	6.8	10.3
Killed Steel		57	29.	13.5	13.6	22	26.	11.5	39.	49.	66	46	5.0	6.0	6.9	9.5
Cast HF-3604 L-A			3.6	7.8	8.4			75.	24.	12.9						
J-55			10.0	26.	25.			340.	69.	32.						

TABLE V
Chromium Steels, Composition and Physical Properties

MATERIAL IDENTIFICATION	COMPOSITION, PERCENT								
	Cr	Ni	Cu	C	Mn	P	S	Si	Mo
Killed steel[1]	0.002	0.006	0.008	0.05	0.30	0.005	0.030	0.006	......
K-398 (UCC)[2]	0.99	0.07	<.01	0.05	0.52	0.006	0.01	0.042	0.01
K-399 (UCC)	2.02	......	......	0.05	0.40n	......	......	0.30n	......
K-400 (UCC)	2.93	......	......	0.06	0.40n	......	......	0.30n	......
K-401 (UCC)	5.00	......	......	0.05	0.40n	......	......	0.30n	......
K-402 (UCC)	7.11	0.07	<.01	0.05	0.60	0.007	0.01	0.27	<.01
K-403 (UCC)	9.84	......	......	0.06	0.40n	......	......	0.30n	......
K-404 (UCC)	13.8	......	......	0.05	0.40n	......	......	0.30n	......
K-405 (UCC)	17.9	0.06	<.01	0.05	0.68	0.008	<.01	0.31	<.01
Cr-5 (Battelle)[3]	5.02	......	......	0.10	0.55	......	......	0.46	0.10
Cr-12 (Battelle)	12.9	0.29	......	0.10	......	......	......	......	......
Cast AW 2023 L-12[4]..	12.48	0.47	......	0.11	0.70	0.016	0.021	0.94	......

MATERIAL	PHYSICAL PROPERTIES			
	Tensile Strength, Psi.	Yield Point, Psi.	Elongation, Percent in 2 In.	Hardness, Brinnel
Cast AW-2023 L-12...	112,000	83,000	19.0	....

[1] Sample furnished by Carnegie-Illinois Steel Corporation.
[2] Samples furnished by Union Carbide and Carbon Research Laboratories, Inc.
[3] Samples furnished by Battelle Memorial Institute.
[4] Sample furnished by Lebanon Steel Foundry.
Abbreviations: n—nominal.

cepts of cumulative weight loss and time are involved. The 7-day tests in all corrosive mediums involved weekly repetition of measurements, the results of which were averaged by graphic methods. The weight losses occurring during each 7-day period, corrected for cleaning losses, were added to provide a cumulative sum that was plotted as a function of the total number of days of exposure in the successive and separate 7-day tests. Any one of the curves in Figures 9, 10, and 11 are examples of such handling of the test data. The curve (Figure 9) for steel K-401 containing 5.00 percent chromium shows that for the first three weighings the weight losses were respectively 62, 95, and 153 milligrams per square decimeter (md). In the fourth and fifth tests, weight losses increased greatly for reasons unknown, and the cumulative losses were 427 and 652 md. Thereafter,

the losses measured in each test were approximately the same, and the plot of cumulative losses was substantially linear in form. If only the results of the first three tests are taken as the measure of the rate of corrosion, the average rate of weight loss is 7.3 mdd. The average of results from the fourth and fifth tests is 36 mdd and obviously unreliable. The measure of rate of corrosion actually used in this report is 22 mdd—the average of the slopes of the curve determined by tangents at the points indicated, one of which was after 13 test periods (91 days) and the other after 21 test periods (147 days).

The principal reason for using the graphic method for averaging the results of the 7-day tests is that it provides a convenient and practicable method for eliminating discordant measurements, such as the first seven that were obtained when

measuring the rate of corrosion of the 5.00-percent chromium steel in propionic acid. Uniform test results provide a linear function when plotted on a cumulative basis so that discordant data can readily be detected. Unusually high weight losses may be the result of temporary failure of the protective current during the electrolytic cleaning process or excessive flaking and chipping of the coupon surfaces while they are being scrubbed with a brush to clean them of the products of corrosion. There are times involving several consecutive coupon exposure periods when corrosion-rate determinations vary consistently from the normal for reasons that are not evident, and although such anomalies provide an interesting and perhaps significant corrosion record they can lead to erroneous conclusions if not detected and eliminated from consideration in estimates of representative averages.

Photographs of coupons of the series of steels containing 0.99 to 17.9 percent chromium taken after 28 consecutive 7-day exposures in propionic acid, carbonic acid, and phenol are shown in Figures 12, 13, and 14. As the surfaces of the coupons were not smooth and even at the beginning of the tests, the roughness which shows in the photographs on coupons containing more than 5.00 percent chromium is not necessarily due to pitting corrosion. Coupons containing 5.00 percent or

TABLE VI
Chromium Steels, Rates of Corrosion

1	2	Average Rate of Corrosion During Indicated Period of Continuous Exposure, mdd														
		Propionic Acid					Carbonic Acid					Phenol				
Material Identification	Percent Chromium	1 dy.	7 dy.	28 dy.	70 dy.	140 dy.	1 dy.	7 dy.	28 dy.	70 dy.	140 dy.	1 dy.	7 dy.	28 dy.	70 dy.	140 dy.
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Killed Steel	0.002	75.	25.	14.4	14.2	19.6	30.	15.4	38.0	39.0	56.	52.	18.9	6.9	6.1	7.2
K-398 (UCC)	0.99	105.	34.	12.2	16.5	22.	200.	158.0	80.0	80.0	67.	48.	17.8	6.0	6.1	6.0
K-399 (UCC)	2.02	120.	36.	18.5	16.4	17.8	520.	240.0	72.0	74.0	53.	33.	19.0	5.6	9.1	5.8
K-400 (UCC)	2.93	90.	35.	16.5	16.0	17.0	490.	230.0	90.0	125.0	43.	23.	16.8	3.0	4.2	5.1
K-401 (UCC)	5.00	30.	22.	18.7	14.1	12.8	410.	161.0	82.0	70.0	37.	5.8	13.5	3.7	4.5	4.9
K-402 (UCC)	7.11	6.6	3.2	4.4	0.63	6.6	65.	21.0	9.2	6.2	9.6	5.0	9.2	1.66	6.0	3.4
K-403 (UCC)	9.84	1.83	0.59	1.27	0.31	0.47	16.	2.4	0.98	0.58	0.57	3.5	4.0	1.35	1.09	2.6
K-404 (UCC)	13.8	3.3	0.40	0.09	0.11	0.04	7.0	0.67	0.29	0.20	0.16	5.0	0.47	0.10	0.10	0.04
K-405 (UCC)	17.9	2.6	0.50	0.10	0.04	0.02	3.8	0.31	0.10	0.00	0.11	3.5	0.21	0.00	0.18	0.02
Cr-5 (Battelle)	5.02	....	2.0	2.9	8.6	....	....	240.0	....	....	....	....	....	....	....	....
Cr-12 (Battelle)	12.9	....	0.38	0.20	0.10	....	....	0.40	....	....	....	....	....	....	....	....
Cast AW-2023 L-12	12.48	....	0.35	0.72	0.20	....	....	0.38	0.26	0.08	....	....	....	....	....	....

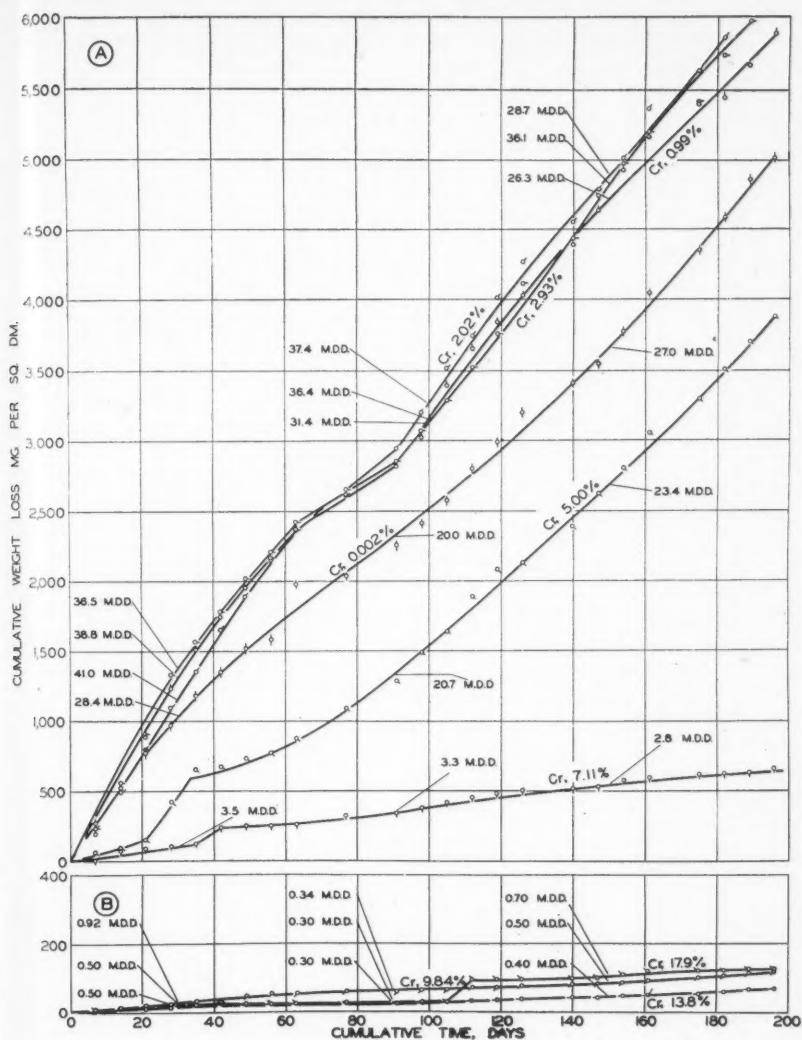CUMULATIVE WEIGHT LOSS MG PER SQ. DM.

Rate

FIGURE 9

Rates of corrosion of chromium steels in a solution of propionic acid (200 ppm) at 130° F. Averages for 7-day tests.

FIGURE 10

Rates of corrosion of chromium steels in an aqueous solution of carbon dioxide at 200 psia and 130° F.
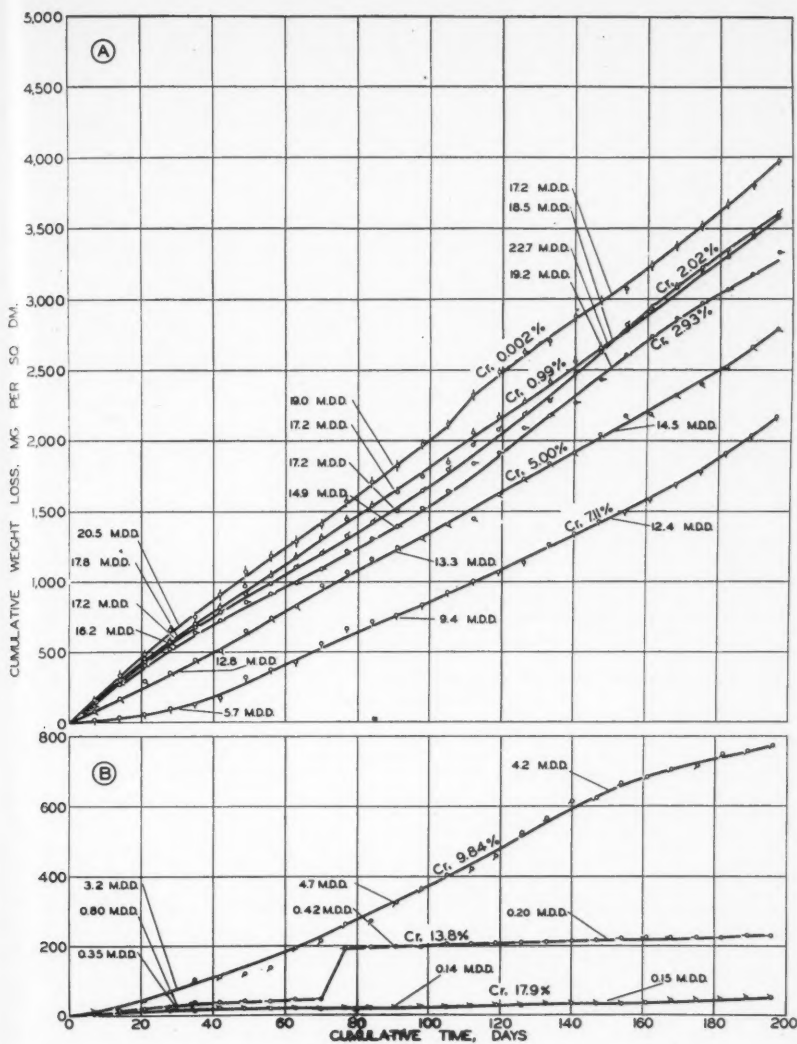Averages for 7-day tests.

FIGURE 11

Rates of corrosion of chromium steels in a solution of phenol (200 ppm) at 130° F. Averages for 7-day tests.
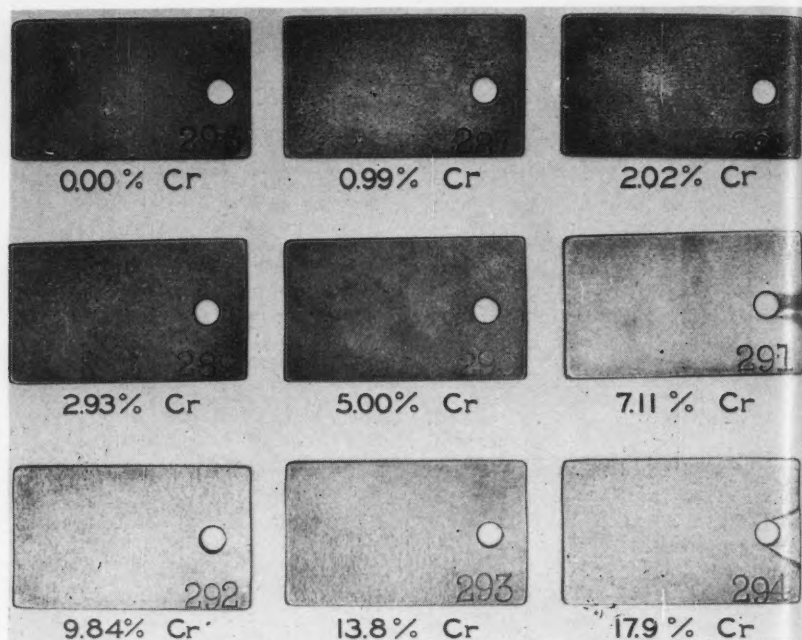
Figure 12—Chromium steel coupons at conclusion of 28 consecutive 7-day exposure tests in propionic acid (200 ppm) at 130° F.

less chromium were noticeably pitted after exposures to carbonic acid; the degree of pitting varied inversely with the chromium content of the steels. Rate of weight loss is a reliable measure of the rate of corrosion of chromium steels and one substantially independent of the period of continuous exposure to corrosive mediums.

From the results of the tests made on chromium steels containing more than 5 percent chromium it is concluded that such steels would be suitable for the manufacture of tubular goods and fittings for gas-condensate wells subject to corrosion.

As shown by Figure 6, the 5.00-percent chromium steel compared favorably with other high-strength steels in its corrosion-resisting properties; but, as indicated in Table VI, the corrosion resistance of chromium steels is increased greatly by moderate increases in the chromium content above 5.00 percent, so that operators buying chromium steel pipe and fittings would find it to their advantage to specify steels containing more than 5 percent chromium.

Tubing is manufactured from two chromium steels containing 6 to 8 percent chromium and 0.45 to 0.65
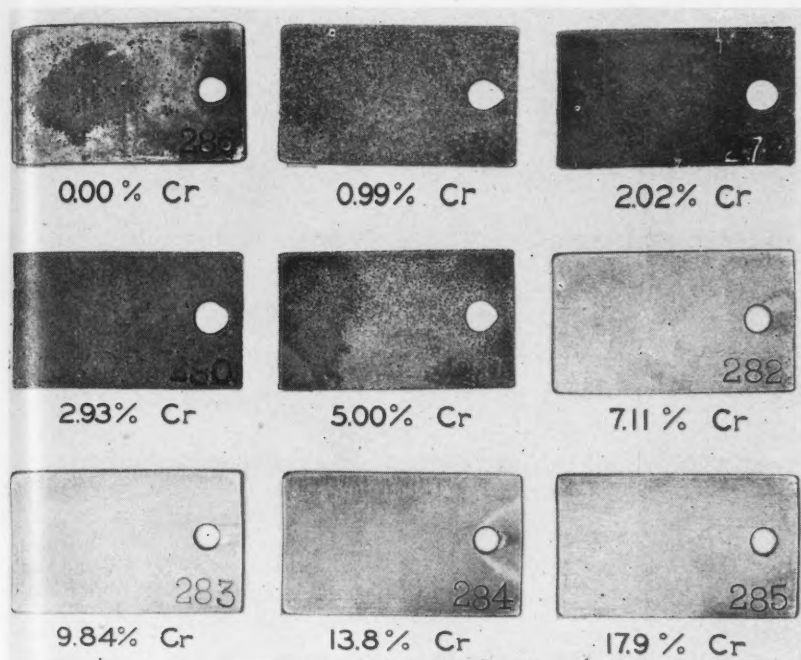
Figure 13—Chromium steel coupons at conclusion of 28 consecutive 7-day exposure tests in carbonic acid under a pressure of 200 psia at 130° F.

percent molybdenum; and 8 to 10 percent chromium and 0.90 to 1.10 percent molybdenum. Physical properties required in API grade J-55 and N-80 tubing can be developed in these chromium-molybdenum steels by heat treating them[9]; they are of the air-hardening type and the desired transition of the metal phases can be obtained in any practical section thickness. Heat treatment consists of air normalizing followed by tempering to obtain the desired physical properties. Examples of certain physical properties that may be developed in the commercial steels by heat treatment are given in Table VII.

Nickel Steels

A series of 11 steels containing nickel in amounts varying from 0.0 to 37.75 percent with all other alloying elements substantially constant was tested to determine the effect of nickel concentrations on the corrosion rates of such steels. Nickel metal (99.4 percent nickel) was included in the tests in order to obtain information on the effectiveness of nickel on steel platings. Tests were made also on three nickel steels that had been heat treated to make them resistant to corrosion. The compositions and physical properties of the nickel steels are given in Table VIII.

Most of the nickel steels were
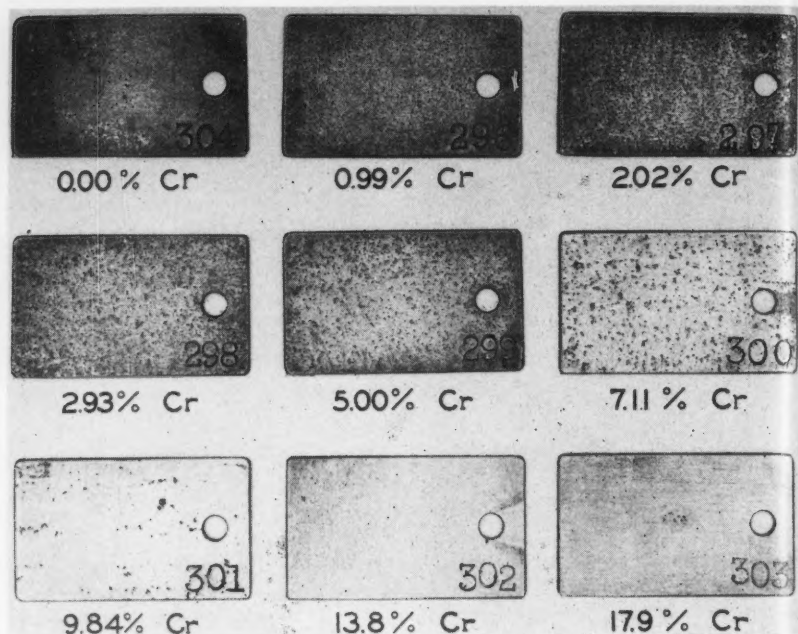
Figure 14—Chromium steel coupons at conclusion of 28 consecutive 7-day exposure tests in phenol (200 ppm) at 130° F.

tested in all three of the corrosive mediums—propionic acid, carbonic acid, and phenol,—and the results of the tests are shown in Table IX. The rates of corrosion of steels containing up to 5 percent nickel are substantially the same. Some increase in corrosion resistance (as indicated by change in rate of weight loss) was gained by increasing the nickel content of steel to 8.5 percent, but the steel containing 37.75 percent nickel was highly resistant to corrosion. Nickel metal was substantially unaffected by solutions of carbonic acid and phenol. The test results did not indicate a significant difference in the rates of corrosion

of the heat-treated steels containing 5.19, 8.34, and 9.09 percent nickel.

The 7-day test data that were averaged to obtain measures of the rates of corrosion of nickel steels in propionic and carbonic acids and phenol are shown graphically in Figures 15, 16, and 17. The weight losses in propionic acid that occured in the first eight of the 7-day tests were somewhat higher than in the tests that followed, but, in general, the plotted data provided substantially linear functions, as shown by Figure 15. The data obtained by exposure of coupons in phenol (Figure 17) also indicated constant rates of corrosion. The low-nickel steels ex-

posed in carbonic acid corroded severely, and coupons from the steels containing less than 8.5 percent nickel were so badly attacked by pitting corrosion that, in some instances, the tests had to be discontinued after five exposure periods. Photographs of the coupons after they were exposed in the three corrosive mediums are shown in Figure 18, 19, and 20.

The cumulative weight-loss curves for some of the nickel steels exposed in carbonic acid record an unusual corrosion history. The curves in sections B, C, and D of Figure 16 show that rates of corrosion were relatively high for the first five to seven exposure periods and thereafter low. The coupons were cleaned at the

end of each 7-day exposure period, so that protection against corrosion by a cumulative film of corrosion products would not be expected in later tests any more than in the first ones. The coupons had been cut

TABLE VII

Approximate Values of Physical Properties That May Be Developed in 7- and 9-Percent Chromium Steels

HEAT TREATMENT, TEMPERATURE, °F.		Tensile Strength, psi.	Yield Point, psi.	Elongation, Percent in 2 In.	Impact Strength, Ft. Lb.
Normalize	Temper				
1,700........	....	186,950	151,500	17	33
1,700........	1,000	200,650	160,500	18	31
1,700........	1,100	136,400	115,000	23	48
1,700........	1,200	113,550	94,000	24	48
1,700........	1,300	108,000	86,250	25	50
1,700........	1,400	96,500	71,400	26	56
N-80 requiremen's, min		100,000	80,000	16	..
J-55 requirements, min.		75,000	55,000	20	..

TABLE VIII
Nickel Steels, Composition and Physical Properties

MATERIAL IDENTIFICATION	COMPOSITION, PERCENT								
	Cr	Ni	Cu	C	Mn	P	S	Si	Mo
G-43 (INC)[1]........	0.0	0.0	0.24	0.06	0.32	0.010	0.023	0.01	......
A-31 (INC)........	<.10	0.05	0.041	0.09	0.35	0.009	0.016	0.05	......
B-32 (INC)........	<.10	0.20	0.038	0.11	0.69	0.011	0.015	0.14	......
C-33 (INC)........	<.10	0.55	0.03	0.14	0.37	0.008	0.018	0.07	......
H-30 (INC)........	0.65	1.18	0.04	0.13	0.45	0.017	0.025	0.23	......
D-28 (INC)........	0.05	1.47	0.03	0.14	0.47	0.014	0.016	0.23	......
J-29 (INC)........	0.09	1.84	0.03	0.16	0.53	0.013	0.009	0.25	0.24
E-20 (INC)........	0.09	3.23	0.07	0.19	0.53	0.016	0.022	0.009	......
F-36 (INC)........	<.10	4.99	0.03	0.13	0.23	0.007	0.014	0.07	......
Ni 8.5 (INC)........	<.10	8.6	<.10	0.10	0.77	0.010	0.024	0.23	<.05
J (INC)........	......	37.75	......	......	......	......	......	......	......
Nickel metal........	......	99.4	0.10	0.10	0.20	.....	0.005	0.05	......
45,479 (PP)[2]........	......	5.19	......	0.174	0.48	0.014	0.020	0.21	......
14,001 (PP)........	0.20	8.34	......	0.09	0.54	0.014	0.016	0.24	0.05
2,000 (PP)........	......	9.09	0.48	0.06	0.27	......	......	0.09	0.50

MATERIAL IDENTIFICATION	PHYSICAL PROPERTIES				
	Heat Treatment	Tensile Strength, Psi.	Yield Point, Psi.	Elongation, Percent in 2 In.	Hardness, Brinnel
Ni 8.5 (INC).................	N 1575° F., D 1075° F.	113,000	92,800	35.0	211-229
45,479 (PP).................	N 1550° F., N 1460° F., D 600° F.	100,000	73,000e	....	205
14,001 (PP).................	N 1550° F., N 1460° F., D 600° F.	140,000e	95,000e	....	286
2,000 (PP).................	N 1550° F., N 1450° F., D 1050° F.	140,000e	95,000e	....	280

[1] Samples furnished by International Nickel Company.
[2] Samples furnished by Phillips Petroleum Company.

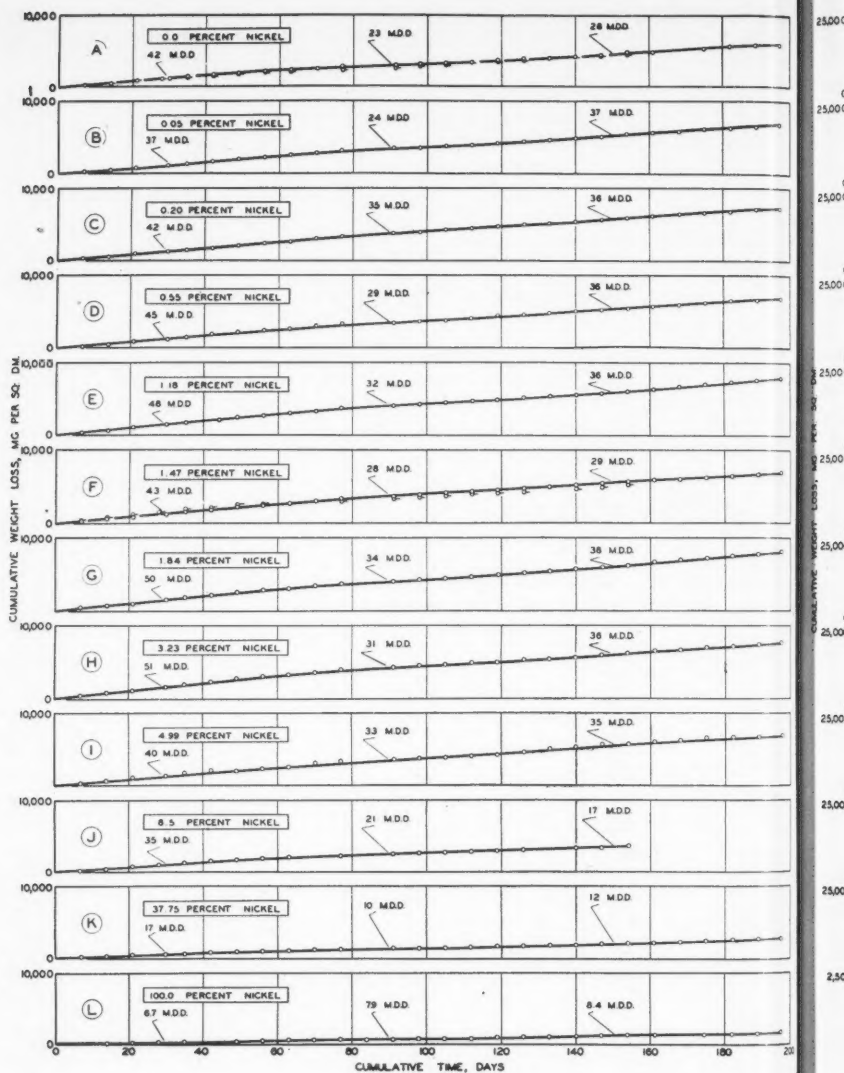Abbreviations: N—Normalized.   D—Drawn   e—Estimated.

FIGURE 15

Rates of corrosion of nickel steels in a solution of propionic acid (200 ppm) at 130° F. Averages for 7-day tests.
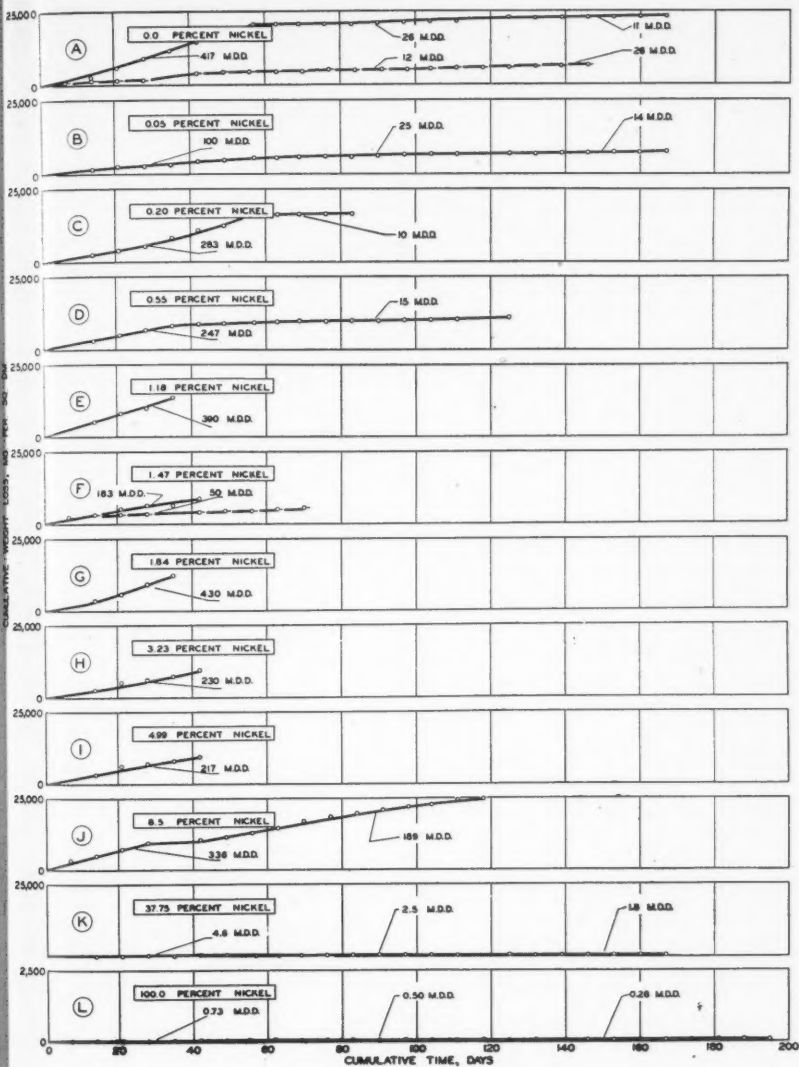
FIGURE 16

Rates of corrosion of nickel steels in an aqueous solution of carbon dioxide at 200 psia and 130° F.
Averages for 7-day tests.

from sheets only 0.031 inch thick, so that the pitting corrosion completely penetrated the coupons, forming many small holes. An impression of the damage done to the coupons can be gained from Figure 19. The reduction in the area of the exposed surface attributable to the holes would account for some but not all of the lowering of corrosion rate. Because of the pitting corrosion, most of which occurred in the first tests when rates of weight loss were high, the relatively low rates of weight loss measured in subsequent tests were not considered indicative of the corrosion resistance of the metals. Accordingly, the slopes of the part of the curves developed in the early test periods were given the greatest weight in estimating the rates of corrosion shown in Table IX for the 7-day tests.

Of the nickel steels tested, the one designated 8.5-percent nickel seems to be the most promising as material for the manufacture of well tubing. Although the 8.5-percent nickel steel is subject to localized corrosion in carbonic acid, the surface of the steel, as shown by the photographs in Figures 18 and 20, is only roughened after 196 days of exposure in propionic acid and phenol. The rates of corrosion of 8.5-percent nickel steel in propionic acid and phenol (Table IX) are

TABLE IX

Nickel Steels, Rates of Corrosion

Material Identification	Percent Nickel	Propionic Acid					Carbonic Acid					Phenol				
		1 dy.	7 dy.	28 dy.	70 dy.	140 dy.	1 dy.	7 dy.	28 dy.	70 dy.	140 dy.	1 dy.	7 dy.	28 dy.	70 dy.	140 dy.
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
G-43 (INC)	0.0	96.	31.	10.8	18.1	19.2	145.	99.	98.	110.	56.	70.	21.	7.8	6.8	6.8
A-31 (INC)	0.05	118.	33.	7.4	16.5	23.	20.	100.	71.	94.	32.	51.	21.	6.2	6.1	6.9
B-32 (INC)	0.20	120.	38.	14.2	20.	22.	95.	280.	95.	82.	54.	70.	21.	3.8	8.0	7.9
C-33 (INC)	0.55	122.	37.	17.8	18.7	22.	80.	250.	83.	58.	44.	58.	21.	7.8	6.9	7.5
H-30 (INC)	1.18	150.	39.	16.9	21.	23.	390.	390.	88.	99.	45.	60.	21.	5.9	6.5	6.4
D-28 (INC)	1.47	145.	33.	21.	19.5	30.	133.	116.	51.	95.	58.	54.	24.	11.5	10.1	9.5
I-29 (INC)	1.84	138.	41.	21.	17.5	28.	440.	430.	178.	66.	50.	57.	22.	7.6	6.6	7.8
E-20 (INC)	3.23	127.	39.	15.6	22.	28.	145.	230.	82.	89.	40.	49.	20.	7.0	6.1	7.0
F-36 (INC)	4.99	123.	36.	20.	17.0	26.	190.	220.	57.	59.	41.	50.	20.	7.8	7.4	7.2
Ni 8.5 (INC)	8.6	74.	24.	12.6	13.6	18.5	370.	260.	48.	55.	32.	75.	18.	6.8	5.3	5.4
J (INC)	37.75	46.	13.	5.0	5.9	7.2	6.0	3.0	1.45	1.77	1.42	8.8	4.0	2.6	3.3	3.3
Nickel Metal	99.4	8.8	7.7	3.4	4.5	4.2	1.00	0.50	0.34	0.37	0.36	0.47	0.14	0.00	0.08	0.07
45.479 (PP)	5.19	....	27.	3.2	2.2	....	....	290.	60.	82.	....	....	....	....	....	....
14,061 (PP)	8.34	....	24.	2.6	2.2	....	....	320.	93.	69.	....	....	....	....	....	....
2,000 (PP)	9.09	....	38.	2.9	1.86	....	....	410.	86.	48.	....	....	....	....	....	....

Average Rate of Corrosion During Indicated Period of Continuous Exposure, mdd

FIGURE 17

Rates of corrosion of nickel steels in a solution of phenol (200 ppm) at 130° F. Averages for 7-day tests.

0.00% Ni	0.05% Ni	0.20% Ni
0.55% Ni	1.18% Ni	1.47% Ni
1.84% Ni	3.23% Ni	4.99% Ni
8.50% Ni	37.75% Ni	100.00% Ni

Figure 18—Nickel-steel coupons at conclusion of 28 consecutive 7-day exposure tests in propionic acid (200 ppm) at 130° F.

about the same as the rates measured in corresponding tests on SAE 1005 and killed steel (Table IV). For corresponding exposures in carbonic acid, the nickel steel was not as resistant to corrosion as the low-carbon steels but showed approximately the same rates of corrosion as the tubing material J-55. As was brought out in the discussion of Figure 6, the worth of 8.5-percent nickel steel for resisting the corrosive attack of carbonic acid may not be indicated by short-period tests because rates of corrosion decrease with time of exposure, perhaps due to the cumulation of a corrosion resistant film or scale on the surface of
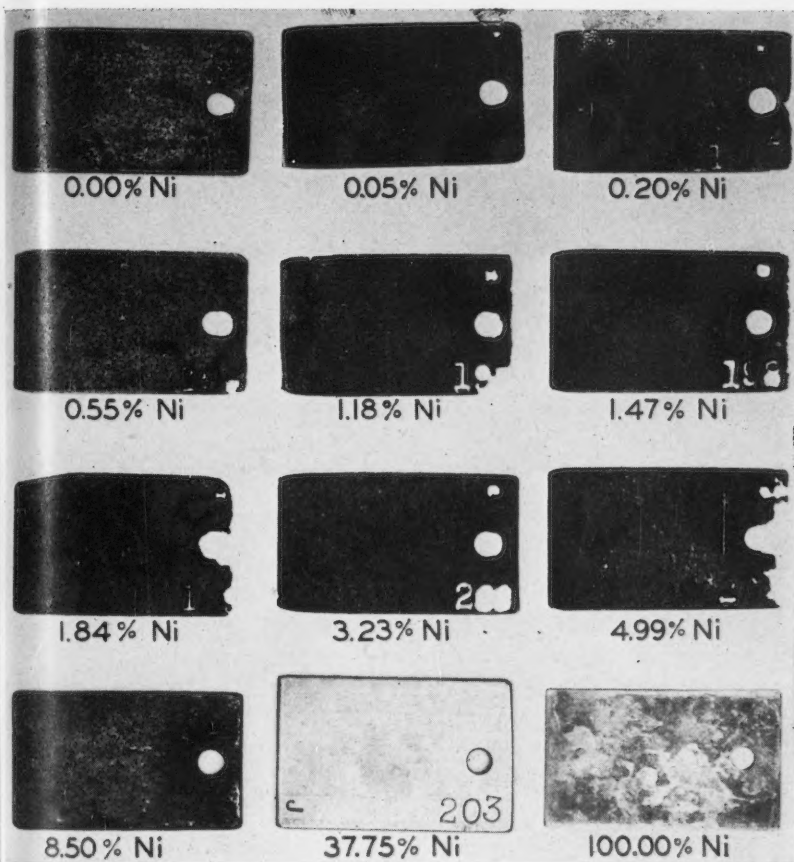
Figure 19—Nickel-steel coupons at conclusion of successive 7-day exposure tests in carbonic acid at a pressure of 200 psia at 130° F.

the coupon. After continuous exposure to carbonic acid for 140 days, the 8.5-percent nickel coupon lost 4480 milligrams of steel per square decimeter of exposed surface, which is the equivalent of a layer of steel only 0.0022 inch thick, assuming uniform distribution of weight loss; because of the localized corrosion that occurred, the steel actually was penetrated to somewhat greater depths. By the end of the 140 days, the rate of corrosion in terms of rate of weight loss had slowed to 6.8 mdd— a rate of weight loss corresponding to 0.0012 inch per year (uniform attack), which is negligible unless in service it is more localized than was indicated by the laboratory tests.

Tubing made from 5-percent and
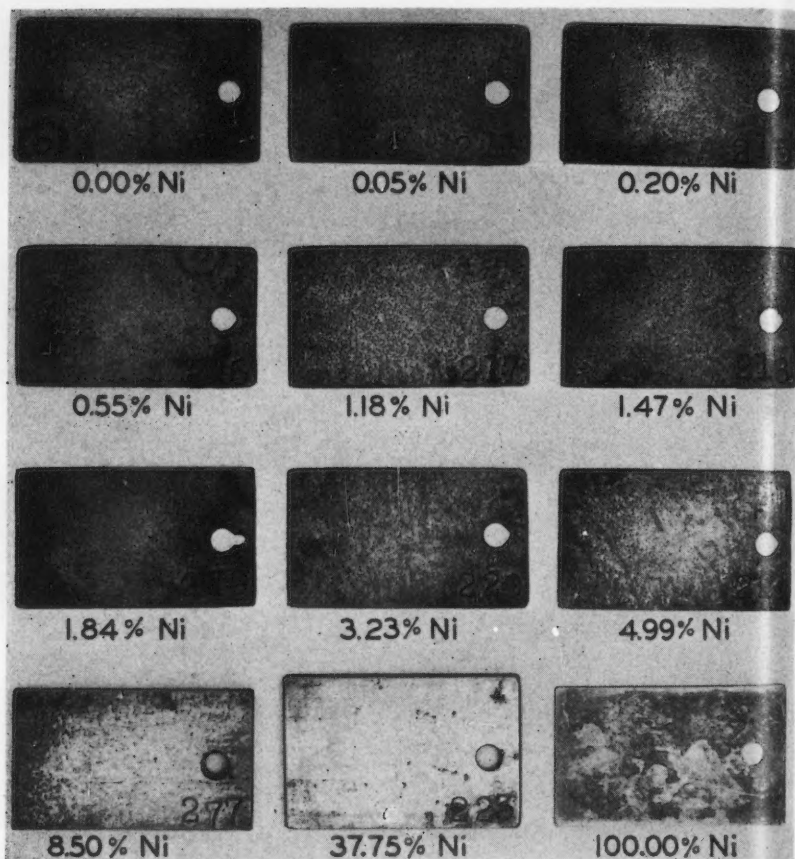
Figure 20—Nickel-steel coupons at conclusion of 28 consecutive 7-day exposure tests in phenol (200 ppm) at 130° F.

9-percent nickel steel[10, 11] is being manufactured for use in gas-condensate wells. Physical properties meeting the requirements of API grade J-55 tubing can be developed in the 5-percent nickel steel by a normalizing treatment; the 9-percent nickel steel is normalized and tempered to provide physical properties exceeding those required in API grade N-80 tubing.[9] Tests made in the field by exposing coupons of metals in the flow stream of wells have indicated that 9-percent nickel steel has relatively high resistance to corrosion by gas-condensate fluids.[12]

TABLE X
Chromium-Nickel Steels, Composition

MATERIAL IDENTIFICATION	COMPOSITION, PERCENT							
	Cr	Ni	Cu	C	Mn	P	S	Si
302-RH (INC)[1]	17.76	9.25	......	0.08	1.09	0.025	0.0'4	0.50
309-JS (INC)	22-24	12.15	......	0.20 m	2.0 m	0.035 m	0.03 m	3.50 m
310-UW (INC)	25.50	21.38	0.15	0.14	0.89	......	0.007	0.53
311-UX (INC)	21.78	24.75	0.22	0.09	0.95	......	0.016	0.47
330-UY (INC)	14.70	33.82	0.07	0.11	0.74	......	0.012	0.55
325-RB (INC)	7.5-9.0	21-23.5	1.5	0.3n	0.7	......	......	1.5

[1] Samples furnished by International Nickel Company.
Abbreviations: m—maximum content. n—nominal.

Chromium-Nickel Steels

A series of six chromium-nickel steels having the compositions given in Table X were tested for their corrosion resistance in propionic and carbonic acids. These costly steels do not have the strength and other physical properties desired of tubing but may find useful application for special fittings and tools.

The rates of corrosion of these stainless-type steels are given in Table XI, where the 7-day test results are averages of weight losses incurred in 14 exposure periods. For none of the steels is the weight loss serious; some of the metals were not even perceptibly attacked by the corrosive mediums.

Copper-Nickel Steels

A series of 26 alloyed steels containing copper and nickel in systematically varied proportions was tested in propionic and carbonic acids. The steels were especially prepared by the Youngstown Sheet and Tube Co. for the laboratory investigations to aid in determining the corrosion resistance that might be attained by steels containing relatively small additions of copper and nickel. The compositions of the metals (designated Y-1 to Y-24) are given in Table XII. Except for metals Y-7, -8, -21, -22, -23, and Y-24, the concentrations of alloying elements other than nickel and copper are substantially constant. The materials Y-6520 and Y-6400 are essen-

TABLE XI
Chromium-Nickel Steels, Rates of Corrosion

1	2	3	4	5	6	7	8	9
	Composition Nominal Percent		Average Rate of Corrosion During Indicated Period of Continuous Exposure, mdd					
			Propionic Acid			Carbonic Acid		
Material Identification	Cr	Ni	7 dy.	28 dy.	79 dy.	7 dy.	28 dy.	70 dy.
302-RH (INC)	18	8	0.00	0.00	0.00	0.00	0.21	0.00
309-JS (INC)	23	14	0.00	0.00	0.00	0.00	0.00	0.00
310-UW (INC)	25	20	0.06	0.00	0.00	0.02	0.00	0.00
311-UX (INC)	20	25	0.02	0.00	0.03	0.11	0.00	0.00
330-UY (INC)	15	34	0.12	0.11	0.06	0.49	0.84	0.03
325-RB (INC)	8	22	5.1	6.72	3.0	14.0	5.4	7.0

TABLE XII

Copper-Nickel Steels,[1] Composition

MATERIAL IDENTIFICATION	COMPOSITION, PERCENT								
	Cr	Ni	Cu	C	Mn	P	S	Si	Mo
Y-6520	......	1.65	0.90	0.09	0.49	0.009	0.031	......	......
Y-6400		1.61	0.88	0.21	0.90	0.008	0.022	0.16	
Y-1	......	0.012	0.03	0.12	0.65	0.007	0.024	0.21	......
Y-2	......	1.99	0.98	0.095	0.65	0.008	0.023	0.20	......
Y-3		3.00	1.48	0.10	0.63	0.007	0.023	0.21	
Y-4		3.99	2.00	0.09	0.58	0.007	0.020	0.20	
Y-5		5.08	2.64	0.08	0.50	0.007	0.027	0.18	
Y-6		5.82	2.98	0.10	0.50	0.008	0.026	0.20	
Y-6x		6.26	3.21	0.10	0.68	0.007	0.023	0.24	
Y-2		1.99	0.98	0.095	0.65	0.008	0.023	0.20	
Y-7		1.98	1.00	0.10	0.58	0.008	0.024	0.18	0.25
Y-8		2.08	1.00	0.105	0.64	0.009	0.028	0.15	0.47
Y-2		1.99	0.98	0.095	0.65	0.008	0.023	0.20	
Y-9		1.99	1.50	0.11	0.59	0.008	0.025	0.17	
Y-10		2.10	2.02	0.11	0.60	0.008	0.028	0.15	
Y-11		1.95	2.48	0.09	0.59	0.008	0.027	0.17	
Y-12		2.01	3.12	0.08	0.59	0.009	0.022	0.18	
Y-13		1.99	3.65	0.09	0.58	0.007	0.027	0.16	
Y-14		1.97	3.96	0.10	0.62	0.007	0.026	0.17	
Y-16x		1.00	3.00	0.11	0.54	0.007	0.025	0.15	
Y-2		1.99	0.98	0.095	0.65	0.008	0.023	0.20	◄
Y-15		2.48	1.00	0.10	0.54	0.007	0.028	0.16	
Y-16		2.97	1.00	0.11	0.66	0.007	0.016	0.21	
Y-17		2.49	1.00	0.08	0.56	0.008	0.027	0.12	
Y-18		4.03	1.12	0.09	0.60	0.007	0.028	0.21	
Y-19		4.44	0.99	0.105	0.63	0.007	0.026	0.20	
Y-20		5.00	0.99	0.085	0.59	0.007	0.027	0.19	
Y-2		1.99	0.98	0.095	0.65	0.008	0.023	0.20	
Y-21		1.98	1.02	0.095	0.64	0.052	0.025	0.21	
Y-22		1.96	1.00	0.09	0.59	0.096	0.027	0.21	
Y-23		0.99	0.52	0.09	0.60	0.098	0.036	0.21	
Y-24	0.99	2.01	1.04	0.10	0.59	0.008	0.028	0.20	......

[1] Samples furnished by Youngstown Sheet and Tube Company.

tially the same, except as to their carbon and manganese contents.

The physical properties of the metals given in Table XIII indicate, in general, that the yield points and percentage elongations are such that the steels satisfy the requirements for API grade J-55 tubing and in some instances those for N-80 tubing. Tensile strengths and yield points of the steels increase as the concentration of copper is increased (series Y-2 to Y-16x), as the concentration of nickel is increased (series Y-2 to Y-20), and as the concentration of both copper and

nickel is increased (series Y-2 to Y-6x).

Difficulty was experienced in hot working some of the materials because of their low nickel-copper ratio. The materials Y-10, -11, -12, -13, -14, and Y-16x were judged by the manufacturers to be definitely unsatisfactory for the production of tubular products. A nickel-copper ratio of 2 or more is considered necessary to provide a steel having optimum hot-working properties.

The results of rate-of-corrosion tests on the copper-nickel steels are given in Table 14. Results reported

TABLE XIII
Copper-Nickel Steels, Physical Properties

MATERIAL IDENTIFICATION	COMPOSITION, APPROX. PERCENT		PHYSICAL PROPERTIES			
	Ni	Cu	Tensile Strength, Psi.	Yield Point,[1] Psi.	Elongation, Percent in 2 In.	Reduction of Area, Percent
Y-6520	1.65	0.90	....	....	....	....
Y-6400	1.61	0.88	....	....	....	....
Y-1	0.0	0.0	61,300	43,200	33.5	70.6
Y-2	2.0	1.0	77,100	58,100	28.2	62.6
Y-3	3.0	1.5	93,000	74,000	24.9	58.5
Y-4	4.0	2.0	112,500	93,500	21.2	54.4
Y-5	5.0	2.5	136,800	118,700	17.0	49.8
Y-6	6.0	3.0	154,400	136,600	13.8	46.7
Y-6x	6.3	3.2	165,600	148,100	11.8	44.7
Y-2	2.0	1.0	77,100	58,100	28.2	62.6
Y-7	2.0	1.0	90,900	77,200	23.3	63.3
Y-8	2.0	1.0	99,900	86,700	21.5	61.1
Y-2	2.0	1.0	77,100	58,100	28.2	62.6
Y-9	2.0	1.5	88,200	77,300	23.6	60.0
Y-10	2.0	2.0	106,400	91,500	21.2	56.5
Y-11	2.0	2.5	117,000	103,000	19.8	53.2
Y-12	2.0	3.0	128,500	117,400	18.7	49.0
Y-13	2.0	3.5	137,300	128,600	18.0	45.6
Y-14	2.0	4.0	142,300	134,700	17.8	43.6
Y-16x	1.0	3.0	126,500	115,000	18.8	49.8
Y-2	2.0	1.0	77,100	58,100	28.2	62.6
Y-15	2.5	1.0	76,300	59,500	30.7	65.0
Y-16	3.0	1.0	79,300	60,300	29.8	63.8
Y-17	3.5	1.0	83,800	62,700	28.6	62.4
Y-18	4.0	1.0	88,500	67,100	27.1	60.6
Y-19	4.5	1.0	93,300	73,000	25.7	59.2
Y-20	5.0	1.0	104,000	87,500	23.8	57.0
Y-2	2.0	1.0	77,100	58,100	28.2	62.6
Y-21	2.0	1.0	81,100	62,400	29.2	61.6
Y-22	2.0	1.0	83,200	60,000	28.7	60.6
Y-23	1.0	0.5	75,800	57,000	33.0	64.3
Y-24	2.0	1.0	113,900	88,400	19.5	53.2

[1] Yield point corresponding to 0.1 percent set.

for the 7-day tests are averages of weight losses measured for 14 exposure periods; results for the 28- and 70-day tests each represent one determination. In propionic acid these copper-nickel steels have about the same rates of weight loss as carbon steel. In carbonic acid, however, the rates of corrosion are higher for the copper-nickel steels than for the low-carbon steels (Table IV) but approximately the same as those for carbon steel J-55.

Varying the content of nickel and copper in the steels within the concentration limits indicated in Table XIV apparently had little effect on the rates of corrosion of the metals. The results of the 7-day tests in carbonic acid for the series Y-2 to Y-16x show a consistent decrease in rate of corrosion with increase in the concentration of alloyed copper; a similar but less definite relation is evident from the results of the same test of the series Y-2 to Y-6x. For all other tests no dependable correlation between composition and rate of corrosion appears possible.

Figures 21 and 22 are photographs of the coupons of the copper-nickel steels after the 7-day tests. Propi-

TABLE XIV
Copper-Nickel Steels, Rates of Corrosion

1	2	3	4	5	6	7	8	9
	Composition, Approximate Percent		Average Rate of Corrosion During Indicated Period of Continuous Exposure, mdd					
			Propionic Acid			Carbonic Acid		
Material Identification	Ni	Cu	7 dy.	28 dy.	70 dy.	7 dy.	28 dy.	70 dy.
Y-6520	1.65	0.90	17.5	21.	24	92	96	54.
Y-6400	1.61	0.88	9.6	58.	26	92	67	9.1
Y-1	0.0	0.0	10.2	19.3	30	198	102	46.
Y-2	2.0	1.0	9.0	21.	31	340	100	22.
Y-3	3.0	1.5	10.5	30.	30	260	71	18.8
Y-4	4.0	2.0	16.0	21.	31	178	45	18.0
Y-5	5.0	2.5	14.5	25.	35	143	48	10.2
Y-6	6.0	3.0	16.0	19.0	32	185	50	7.5
Y-6x	6.3	3.2	11.5	19.7	23	180	100	12.5
Y-2	2.0	1.0	9.0	21.	31	340	100	22.
Y-7	2.0	1.0	10.8	24.	35	230	34	20.
Y-8	2.0	1.0	12.0	23.	40	280	47	15.8
Y-2	2.0	1.0	9.0	21.	31	340	100	22.
Y-9	2.0	1.5	8.5	19.9	29	240	32	21.
Y-10	2.0	2.0	12.2	27.	29	162	31	22.
Y-11	2.0	2.5	11.0	24.	30	175	54	16.6
Y-12	2.0	3.0	11.5	25.	28	140	44	11.6
Y-13	2.0	3.5	16.2	28.	34	128	42	6.6
Y-14	2.0	4.0	15.0	27.	34	107	54	10.1
Y-16x	1.0	3.0	14.7	23.	30	100	26	13.8
Y-2	2.0	1.0	9.0	21.	31	340	100	22.
Y-15	2.5	1.0	15.1	22.	27	128	55	13.5
Y-16	3.0	1.0	15.0	20.	30	140	94	10.2
Y-17	3.5	1.0	11.5	22.	28	140	52	5.1
Y-18	4.0	1.0	15.1	22.	25	97	33	17.4
Y-19	4.5	1.0	12.0	23.	32	165	42	7.5
Y-20	5.0	1.0	11.2	18.9	23	134	39	15.0
Y-2	2.0	1.0	9.0	21.	31	340	100	22.
Y-21	2.0	1.0	7.8	24.	25	210	111	9.2
Y-22	2.0	1.0	11.0	24.	24	320	121	6.9
Y-23	1.0	0.5	11.0	18.3	26	200	75	13.8
Y-24	2.0	1.0	8.5	23.	27	172	62	12.6

onic acid caused considerable roughening of the coupons but not the destruction that resulted when the same materials were exposed in carbonic acid. As shown in Figure 22, the metal losses resulting from exposure to carbonic acid were localized and greatest in areas near the hole drilled in the coupon or about the stamped identification mark. The contours of some of the depressions resulting from the localized corrosion indicated that the products of corrosion had loosened in flakes as though the metal itself were laminated. The microstructure of alloy Y-6400 shown in Figure 8 suggests the possibility that, as a result of corrosive action, cleavage might develop in one of the planes of the interface between the metal phases.

With reference to Table XIV and the results of corrosion tests in carbonic acid, the low rates of corrosion measured in the 70-day test on some of the coupons make it appear that the coupons lost less weight in 70 days of exposure than they did in 7- and 28-day exposure periods. No satisfactory explanation can be given for this relation of the test results; but the authors believe that
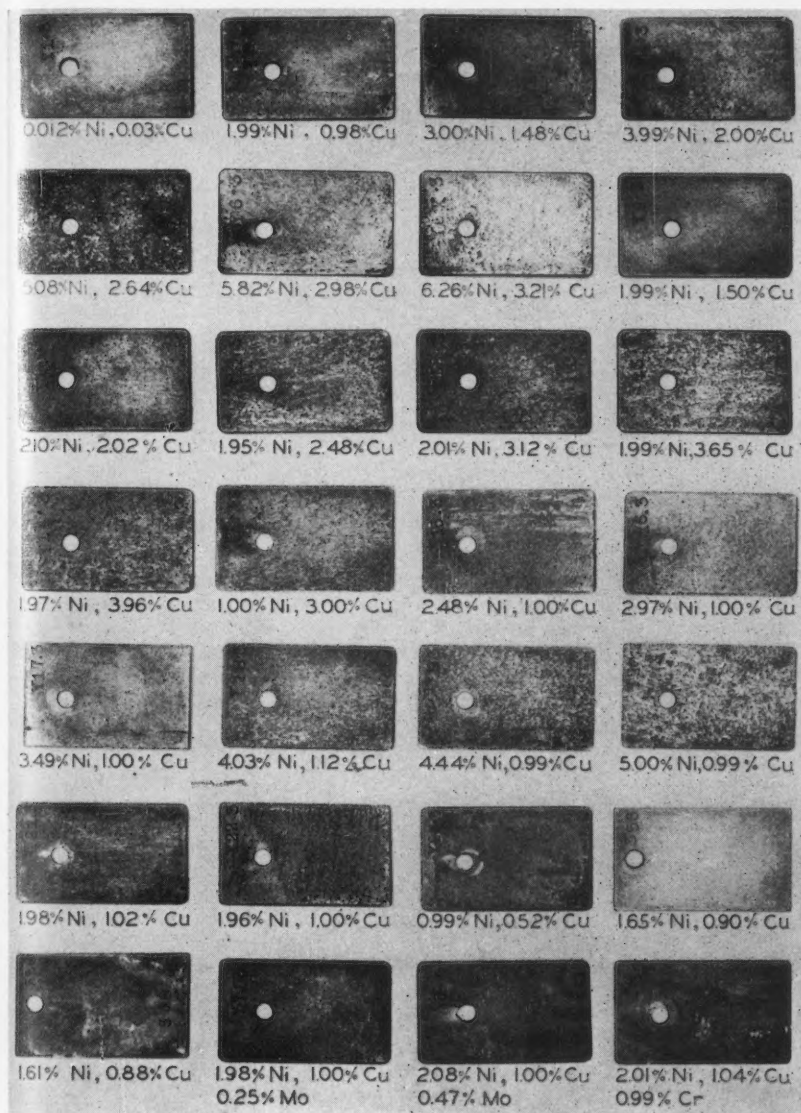
FIGURE 21

Coupons of copper-nickel steel at conclusion of 14 consecutive 7-day exposure tests in propionic acid
(200 ppm) at 130° F.
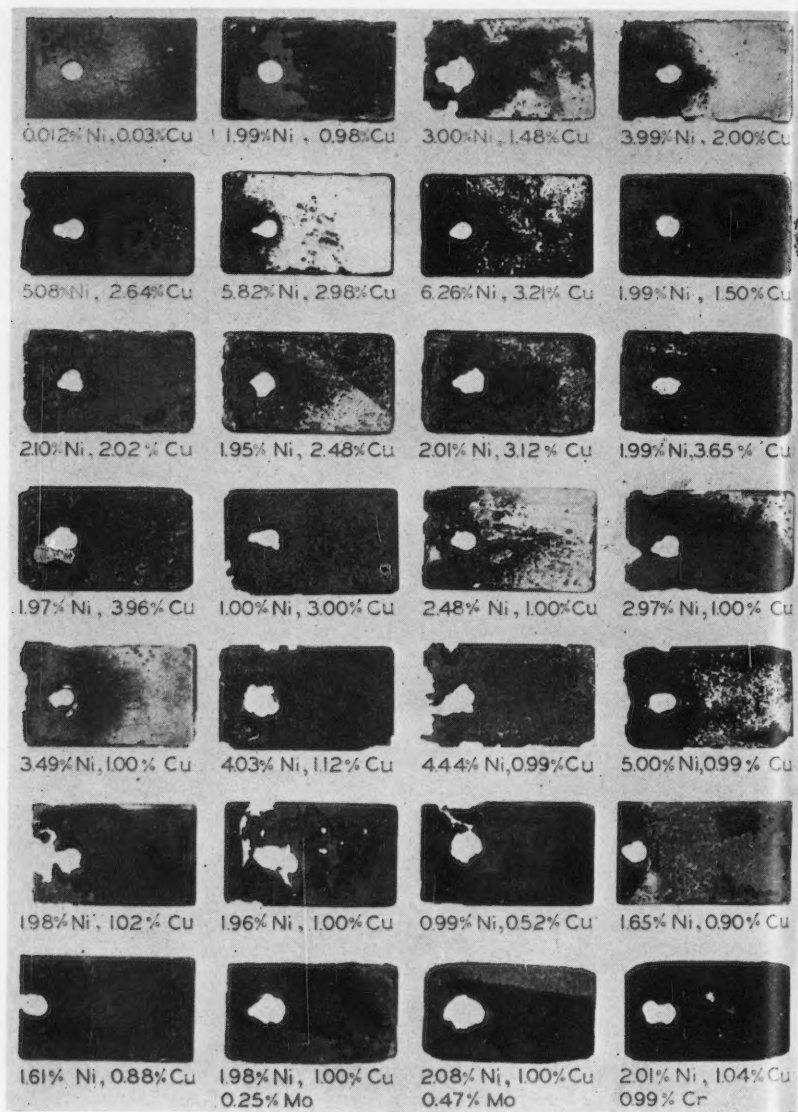
FIGURE 22

Coupons of copper-nickel steel at conclusion of 14 consecutive 7-day exposure tests in carbonic acid under a pressure of 200 psia at 130° F.

TABLE XV

Copper-Nickel Alloys, Composition and Physical Properties

MATERIAL IDENTIFICATION	COMPOSITION, PERCENT		PHIYSCAL PROPERTIES[2]			
	Cu	Ni	Tensile Strength, Psi.	Yield Point Psi.	Elongation, Percent in 2 In.	Hardness, Brinnel
T 15912 (INC)[1]	90n	10	....	....	....	....
CP (INC)	80n	20	....	....	....	....
CN (INC)	70n	30	70,000	50,000	20	150
KO (INC)	55n	45	85,000	65,000	20	....
M (INC)	33n	67	100,000	80,000	25	190

[1] Samples furnished by International Nickel Company.
[2] The values of properties given are average for the cold-drawn state of the metals.
Abbreviations: n=nominal.

the results of short-time tests frequently were high because uncorroded metal, possibly in flake form, was removed from the coupons along with the corrosion products. As is shown in Table I, the rate of corrosion of copper-nickel steels in carbonic acid decreases with period of exposure, but it seems doubtful if this characteristic would have any practical value where a moving fluid, as in the tubing of a well, eroded protective but loosely attached corrosion products. The high rates of weight loss and the localized corrosion found characteristic of the low-copper-nickel steels do not indicate that they would be satisfactory materials for the manufacture of tubing for gas-condensate wells subject to corrosion.

Copper-Nickel Alloys

A series of five copper-nickel alloys containing 33 to 90 percent copper was tested in propionic and carbonic acid corrosive mediums. The composition and physical properties of the alloys are given in Table XV, and the results of the corrosion tests are listed in Table XVI. The alloys are highly resistant to attack by carbonic acid and exhibit good resistance to corrosion by propionic acid. The range of physical properties of copper-nickel steels that can be obtained by varying the copper-nickel ratio suggests that they may be suitable for special applications in the manufacture of valves and Christmas tree accessories. Such uses should, of course, be governed by the consideration that under fa-

TABLE XVI

Copper-Nickel Alloys, Rates of Corrosion

1	2	3	4	5	6	7	8	9
	Composition, Percent		Average Rate of Corrosion During Indicated Period of Continuous Exposure, mdd					
			Propionic Acid			Carbonic Acid		
Material Identification	Cu	Ni	7 dy.	28 dy.	70 dy.	7 dy.	28 dy.	70 dy.
T 15912 (INC)	90	10	6.0	4.0	4.1	0.81	0.53	0.35
CP (INC)	80	20	6.8	5.0	5.0	0.50	0.49	0.42
CN (INC)	70	30	5.6	4.4	4.1	0.38	0.28	0.34
KO (INC)	55	45	4.7	5.4	5.9	0.18	0.21	0.25
M (INC)	33	67	2.2	4.7	4.8	0.00	0.07	0.20

TABLE XVII
Rates of Corrosion of Steel Induced by Adjacent Plated Surfaces

Percent of Steel Surface Exposed	RATE OF CORROSION IN INDICATED SOLUTIONS, mdd		
	Propionic Acid	Carbonic Acid	Phenol
Zinc Plated			
0	25	53	16
100	33	47	22
48	56	122	31
28	64	131	44
7	26	38	23
Copper Plated			
0	9.7	1.24	2.8
100	19.3	11.0	11.8
48	18.4	16.5	17.0
28	35.	32.	25.
7	98.	104.	84.
Nickel Plated			
0	7.7	0.50	0.14
100	28.	33.	18.8
48	70.	109.	36.
28	46.	320.	43.
7	192.	610.	260.

Plating Material	FRACTIONAL INCREASE IN RATE OF CORROSION OF EXPOSED STEEL SURFACE THAT IS 7.0 PERCENT OF TOTAL SURFACE		
	Propionic Acid	Carbonic Acid	Phenol
Zinc	0.77	0.81	1.03
Copper	5.1	9.4	7.1
Nickel	6.8	18.7	13.8

vorable circumstances serious galvanic corrosion can be induced in less noble metals by contact with the copper-nickel alloys.

Plated Steels

Platings are being considered by the industry as a means of protecting steel against corrosion by gas-condensate fluids. A plate of copper or nickel on carbon steel provides a corrosion-resistant covering for a high-tensile strength and economical tubing material. Steels plated with copper and nickel or coated with zinc were subjected to the 7-day test in the three corrosive mediums to determine the corrosion resistance of the coverings. The test results are given in Table XVII opposite the designations 0.0 percent of steel surface exposed.

In general, the corrosion resistance of the plated and coated steels was closely related to the rates of corrosion of the covering materials. The coating obtained by galvanizing is an alloy of iron and zinc and usually is anodic with respect to the steel which it covers. This coating was attacked rapidly and in patches, particularly by carbonic acid; and, although it may have minimized pitting of the steel, it did not last long enough to have much benefit as a protective coating. Iron as well as zinc losses were represented in the data obtained on the rate of corrosion of the galvanized steel. The weight losses of the copper-plated coupons were due almost entirely to losses of copper, and the rates of corrosion of the copper-plated and copper metal coupons were found to be substantially alike. The nickel-plated coupon offered high resistance to corrosion, but the coating was not as resistant as the nickel metal itself.

As nickel and copper platings are cathodic with respect to carbon steel, it is important to know if the rate of corrosion of steel is seriously increased as a result of galvanic effects at imperfections in a plating or at points where tools or instruments used inside tubing scratched or otherwise damaged the plating and exposed the underlying steel. As the area of the steel surface exposed (the anode) would be small as compared with the area of the plate (the cathode), the galvanic current density at the anode would be high and accompanied by con-

version of iron to corrosion products at an abnormally high rate.

Results of some special tests designed to determine the rates of corrosion of steel induced by adjacent plated surfaces are given in Table XVII. In preparing the coupons for the tests, the plating was removed from areas of some of them by means of a lathe to provide plating patterns like those illustrated in Figure 23. The coupons then were subjected to the 7-day corrosion test in propionic acid, carbonic acid, and phenol, to determine the respective rates of corrosion.

Test results were interpreted by means of the equation,

$$cAR_p + (1-c)AR_g = AR \qquad [1]$$

where,

$A =$ area of total surface of coupon, square decimeters,

$c =$ fraction of area covered with plate,

$R =$ rate of corrosion of partially plated coupon, mdd,

$R_p =$ rate of corrosion of a coupon completely covered with a plate, mdd,

$R_g =$ rate of corrosion of steel due to galvanic effects, mdd.

Equation 1 states that the total weight lost by the coupon due to corrosion equals the weight of plating plus the weight of steel converted to corrosion products. The rate of corrosion of steel due to galvanic effects was computed by using the following equation, which was derived from equation 1:

$$R_g = \frac{R - cR_p}{1 - c} \qquad [2]$$

The rates of corrosion indicated in Table XVII for 0.0 percent of steel surface exposed correspond to values of R_p, and those for steel surfaces 100 percent exposed are the measured normal rates of corrosion of the steel that prevail when no plating material is present. The other corrosion rates given in the table are values of R_g for the indicated percentages of steel surfaces exposed.

It was not practicable to clean the zinc-coated coupons in the electrolytic bath, and the products of corrosion had to be removed by hand-scrubbing the coupons with a brush; accordingly, the determinations of weight losses after 7-day exposure periods were somewhat erratic. Some of the results shown in Table XVII indicate an increase in the rate of corrosion of steel due to partial plating, despite the usually anodic nature of the surface alloy formed in galvanizing.

Data for copper and nickel platings indicate that imperfections in the plating increase appreciably the rate of corrosion of exposed steel surfaces, and the smaller the percentage of surface exposed the higher the rate of corrosion of the exposed surface. Data obtained on copper-plated steel exposed in carbonic acid are an example; a steel surface that was 28 percent of a total surface corroded at the rate of 32 mdd, whereas when the exposed surface was only 7 percent of the total surface, the rate of corrosion was 104 mdd. As compared with the rate of corrosion of bare steel (11.0 mdd) not adjacent to plated surfaces, the rate of corrosion increased in the ratios 2.9 and 9.4 respectively.

The authors' findings do not in-

dicate that plated steels should not be used in gas-condensate wells subject to corrosion, but they do warn that caution should be exercised in selecting their application. If a cathodic plating provides a complete surface coverage which probably will not be pierced or partly removed by abrasion, the plate will afford a desirable protection for steel surfaces. The cited example of copper plating for resisting carbonic acid attack shows that the rate of corrosion can be reduced from 11.0 mdd to 1.24 mdd, or 89 percent, by plating; on the basis of similar tests, nickel plating reduced the rate of corrosion of steel from 33 mdd to 0.50 mdd, or 98 percent.

Effect of Sodium Chloride on the Rate of Corrosion of Alloyed Steels

Tests were made to determine the rates of corrosion of chromium and nickel steels in corrosive mediums containing different concentrations of sodium chloride to determine if sodium chloride brines, produced with corrosive gas-condensate fluids, increase or otherwise modify rates of corrosion of alloy steels. To provide data for comparison, similar tests also were made on carbon steel SAE 1005. The results of the tests in carbonic and propionic acid corrosive mediums are shown in Table XVIII.

Except for the addition of sodium chloride to the corrosive mediums, the test procedures were standard in every respect. In propionic acid the rates of corrosion of carbon steel SAE 1005 seem to have been suppressed in direct proportion to the concentration of sodium chloride in

TABLE XVIII

Effect of Sodium Chloride on the Rates of Corrosion of Carbon, Chromium, and Nickel Steels

1	2	3	4	5	6	7
Concentration of Sodium Chloride, p.p.m.	Average Rate of Corrosion During Indicated Period of Continuous Exposure, mdd					
	Propionic Acid			Carbonic Acid		
	7 dy.	28 dy.	70 dy.	7 dy.	28 dy.	70 dy.
Carbon Steel, SAE 10v5						
0...	30.	13.0	12.7	9.1	18.4	28
200...	14.0	.....	.....	12.4	.....	....
2,000...	14.1	.....	.....	11.8	.....	....
20,000...	7.8	.....	.....	9.3	.....	....
200,000...	.....	.....	.....	26.	.....	....
Chromium Steel, K-403, 9.84 Percent Chromium						
0...	0.59	1.27	0.31	2.4	0.98	0.5
1,000...	8.6	4.8	5.4	3.9	2.1	0.5
10,000...	11.6	8.3	6.1	14.0	3.2	0.9
100,000...	14.3	10.2	9.0	19.3	6.2	4.8
Nickel Steel, Ni 8.5, 8.6 Percent Nickel						
0...	24.	12.6	13.6	260	48.	55.
1,000...	4.4	43.	28.	320	22.	2.9
10,000...	5.5	21.	31.	120	48.	7.2
100,000...	7.5	19.7	23.	440	61.	4.0

the corrosive medium. Corrosion rates of the carbon steel in carbonic acid were not significantly affected by sodium chloride in concentrations up to 20,000 ppm.

The rate of corrosion of chromium steel K-403 (9.84 percent chromium) in both propionic and carbonic acid mediums was greatest in the mediums containing the highest concentrations of sodium chloride. The percentage increase was approximately the same irrespective of the period of the test. The increase in the rate of weight loss was greatest in carbonic acid and amounted to a change from 2.4 mdd, determined in the standard solution, to 19.3 mdd in a solution containing 100,000 ppm of sodium chloride. There was evidence of localized attack on the edges of the coupons exposed in propionic and carbonic acids containing the highest concentration of sodium chloride.

The rate of weight loss of the steel containing 8.6 percent nickel was affected in different ways, depending on the corrosive medium and the period of test. In propionic acid the rate of weight loss as shown by the 7-day test decreased on addition of sodium chloride, and for the 70-day test the rate increased. The time-weight loss curve (Figure 5, curve 1, for example) for the data obtained in a propionic acid medium containing 100,000 ppm of sodium chloride showed increasing rate and had greater slope than the corresponding curve of results obtained in a corrosive medium of propionic acid only. Therefore, the nickel steel might corrode at high rates if exposed in a concentrated sodium chloride and propionic acid solution for long periods. There was no marked difference in the rates of corrosion measured for given periods with different concentrations of sodium chloride in carbonic acid. Possible exceptions are the data for the 70-day test, which showed a rate of weight loss of 55 mdd in propionic acid as compared with much lower values for all data obtained in brine solutions.

In general, sodium chloride brines apparently will not seriously accelerate the rate of corrosion of the steels likely to be used in the manufacture of tubing for gas-condensate wells. Although the rates of corrosion of the chromium steel were increased, the maximum rate measured in the most concentrated salt solutions (19.3 mdd) was not high for an alloy steel that corrodes uniformly. A high concentration of sodium chloride caused the rate of corrosion of the nickel steel in pro-pionic acid to increase from 13.6 to only 23 mdd in one test, but data obtained by exposures in carbonic acid did not show marked corrosion acceleration.

Composition of Metals and the Tendency to Wet with Condensate

The liquid-water phase of flowing gas-condensate fluid is the corrosive phase, and if a film of hydrocarbon condensate covers a metal surface so that water does not come in contact with it, the metal will not corrode. To determine whether certain alloys were more susceptible than others to preferential wetting by condensate, wetting tests were made on the 11 metals listed in Table XIX by the method described by Rogers and Waldrip[13] and used in the laboratory of the Gulf Oil Company at Houston, Tex.

After a clean metal specimen had been submerged in water from a well in the Moore field, Orchard, Tex., to provide a water-wet surface, drops of hydrocarbon condensate from the same well were caused to come in contact with the metal, and observations were taken through a microscope to see if the hydrocarbon liquid tended to displace the water film and wet the metal surface. By means of a graduated scale in the optical system of the microscope, the maximum dimensions of the drop were measured perpendicular and parallel to the metal surface. These dimensions corresponded to the height, h, and the diameter, d, of the hydrocarbon drop resting against the under surface of the metal specimen, which was mounted horizontally in the well water.

The drop-size ratios recorded in the last column of Table XIX are values of the function 2h/d. A value of 2 for the ratio would indicate point contact only between the hydrocarbon drop and the metal surface; a value of 1 would indicate that the drop had assumed the shape of a hemisphere and had displaced water from the metal surface. All values of the drop-size ratios reported in Table XIX are slightly less than 2, indicating that the hydrocarbon condensate had little tendency to wet the metal surfaces. Only Everdur Alloy 1010, containing 95.83 percent copper, and K-Monel, containing 33 percent copper, seemed at all susceptible to wetting by hydrocarbons. The drop-size ratios for these metals (1.762 and 1.876, respectively) do not indicate that condensate hydrocarbons would displace water from the metal surfaces and protect the metal against corrosion.

The materials listed in Table XIX

TABLE XIX
Metal Composition and Wetting Tendency of Hydrocarbon Condensate[1]

Material Identification	COMPOSITION, PERCENT				Drop Size Ratio
	Cr	Ni	Cu	Other	
J-55	.....	.....	.....	C, 0.46	1.923
Killed steel	.....	.....	.....	C, 0.05	1.949
K-403	9.84	.....	.....	.....	1.961
Ni 8.5	<.10	8.6	<.10	.....	1.957
Nickel metal	.....	99.4	0.10	.....	1.929
302-RH	17.76	9.25	.....	.....	1.900
Y-2	.....	1.99	0.98	.....	1.935
K-Monel (aged)	.....	67.0	33.0	.....	1.876
Everdur Alloy 1010	.....	.....	95.83	.....	1.762
Alclad 3S-H14 (coating)[2]	.....	.....	.....	A1, 98.6	.....[4]
Zinc Plate[3]	.....	.....	.....	.....	1.930[5]

[1] Data provided by W. F. Rogers and H. E. Waldrip o the Gulf Oil Co., Houston, Texas.
[2] An aluminum alloy with an anodic coating that contains, in addition to aluminum, elements in the following percentages: Cu, 0.01; Si, 0.12; Zn, 1.09; Fe, 0.15.
[3] Galvanized steel sheet.
[4] On two attempts all condensate drops developed gas bubbles and rolled off the plate. The specimen was covered with tiny gas bubbles.
[5] Several of the condensate drops developed gas bubbles. The specimen developed several tiny gas bubbles.

were selected to determine the effects of aluminum, chromium, copper, nickel, and zinc on the hydrocarbon-wetting tendency of the metals in which these elements were alloyed. With the possible exception of the copper-alloyed metals, it does not appear that corrosion resistance to gas-condensate fluids can be expected by the use of common alloying substances to induce preferential wetting of steel by hydrocarbons.

Susceptibility to Corrosive Attack of Well-Treating Acid

A factor that should be considered in selecting alloy tubing for service in gas-condensate wells is the resistance of the alloy to the corrosive action of hydrochloric acid. As shown by Table XX, the rates of weight loss of 19 representative steels, alloys, and alloy steels were determined in 15-percent acid with four different commercial inhibitors at 130° and 300° F. The data obtained indicate the effect of alloying materials, alloy content, and temperature of reaction on the susceptibility of the metals to attack by the acid usually used in treating wells.

To determine the rate of weight loss of a metal, a weighed coupon having a surface area of 0.3 to 0.5 square decimeter was exposed in 900 ml of the acid for six hours, after which the coupon was boiled for two hours in an aqueous solution containing 5 percent soda ash to remove any film from the surface of the metal. The coupon then was cleaned electrolytically and weighed. The results shown in Table XX are averages of two determinations. New

TABLE XX
Rates of Corrosion of Metals in Inhibited 15-Percent Hydrochloric Acid[1]

1	2	3	4	5	6	7	8	9
				Rate of Corrosion at 130° F. with 0.40 Percent Concentration of Indicated Inhibitor, mdd				Corrosion Rate at 300° F. with Sodium Arsenite (0.80 pct.), mdd
	Composition, Percent							
Material Identification	Cr	Ni	Cu	Sodium Arsenite	Copper Amine	N-S Aliphatic	N-S Aromatic	
Carbon Steels:								
J-55	....	....	....	158	680	810	2,600	910
Killed Steel	....	....	....	103	410	430	400	200
Chromium Steels:								
K-401	5.00	....	....	260	690	2,100	570	830
K-402	7.11	0.07	<.01	195	730	3,100	1,400	650
K-403	9.84	....	....	330	1,070	3,500	1,480	220
K-404	13.8	....	....	620	4,100	1,930	6,700	260
K-405	17.9	0.06	<.01	1,150	14,100	7,500	3,400	750
Cast A W-2023 L-12	12.48	0.47	....	230	610	1,670	670	760
Nickel Steels:								
F-36	<.10	4.99	0.03	166	400	148	300	1,130
Ni 8.5	<.10	8.6	<.10	1,920	4,300	6,000	6,500	1,440
J	....	37.75	....	85	280	210	200	1,140
Chromium-Nickel Steels:								
302-RH	17.76	9.25	....	191	188	73	194	1,270
325-RB	8.0	22.	....	210	470	260	2,700	1,120
Copper-Nickel Steels:								
Y-2	....	1.99	0.98	430	610	124	650	840
Y-6x	....	6.26	3.21	360	1,230	630	1,350	1,490
Y-14	....	1.97	3.96	670	1,000	410	830	1,040
Y-20	....	5.00	0.99	340	1,220	250	1,000	1,060
Copper-Nickel Alloys:								
K-Monel (aged)	....	67.	33.	89	200	53	150	216,000
T 15912	....	10.	90.	113	300	11	210	90,000

[1] Data provided by P. H. Cardwell and associates of Dowell Inc., Tulsa, Okla.

solutions were used for each weight-loss determination, even though the acid consumed in each test was less than 1.0 percent of the available acid. The tests run at 300° F. were performed in stainless-steel, glass-lined pressure vessels.

The inhibitors listed in Table XX were dissolved in the 15-percent hydrochloric acid in a concentration of 0.4 percent for the tests at 130° F., and sodium arsenite in a concentration of 0.8 percent was used for the tests at 300° F. These concentration percentages were based on volumes of the commercial inhibitor solutions rather than on the actual weights and volumes of the active inhibitor materials. For example, the sodium arsenite inhibitor consisted of 8 pounds of arsenic trioxide to a gallon of the inhibitor. The copper

amine inhibitor was a proprietary material. The N-S aliphatic inhibitor was a solution of symmetrical dinormalbutyl thiourea and amines. The effective material in the N-S aromatic inhibitor was an aromatic compound containing nitrogen and sulphur.

A saturated hydrocarbon sulfonate was used in the acid as a wetting agent in a concentration of 0.1 percent by volume. The function of this wetting agent has been described by Cardwell and Eilers.[14]

At 130° F., sodium arsenite protected the metals against corrosion by hydrochloric acid more completely than any of the other three inhibitors. The copper-nickel alloys were not protected when the temperature was increased to 300° F., although the concentration of so-

dium arsenite in the hydrochloric acid was increased for the exposure tests at the higher temperature. Of the chromium steels tested, the one containing the most chromium (17.9 percent) had the highest rate of weight loss (1150 mdd). The nickel steel containing 8.6 percent nickel had a rate of weight loss of 1920 mdd, the highest for the nickel steels. The carbon steels, including J-55, and the chromium-nickel steels were subject to relatively low rates of weight loss when exposed to inhibited hydrochloric acid.

The concentration of the sodium arsenite inhibitor in the 15-percent solution of hydrochloric acid was doubled for the corrosion tests at 300° F., and it was found that the rates of corrosion of the metals likely to be used in the manufacture of tubing were not greatly increased. At 300° F., carbon steel J-55 was attacked at 4.5 times the rate of corrosion of killed steel; at 130° F., J-55 was attacked at 1.5 times the rate of corrosion of killed steel. These rates of corrosion of the carbon steels in a hydrochloric acid solution containing sodium arsenite as an inhibitor differ in the same way as the rates of corrosion of the same steels in carbonic acid (Table IV). As discussed in connection with Figure 8, the difference in the carbon content of the steels may account for the difference in their rates of corrosion in carbonic and hydrochloric acids.

At a reaction temperature of 300° F. the rates of weight loss of the 17.9-percent chromium steel and of the 8.6-percent nickel steel were less than they were at 130° F. Although the rates of corrosion of most of the metals were greater at 300° F. than at 130° F., the use of 0.8 percent of sodium arsenite as the inhibitor for the hydrochloric acid limited the metal losses to negligible quantities. The coupons did not show evidence of localized corrosion and the depth to which surface metal would be removed in a period of 24 hours at a corrosion rate of 1000 mdd uniform attack is 0.0005 inch.

Acknowledgments

Figure 23—Coupons used in determining rates of corrosion of steel induced by adjacent plated surfaces.

the tables giving the composition of the metals.

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DISCUSSION

By F. L. LaQue★

These authors have provided a great deal of much needed data on the behavior of a large number of metals and alloys when in contact with corrosive media that may be encountered in gas-condensate wells. They have established base lines pertaining to the conditions of their laboratory tests which will be highly useful in further attacks on the problem by other investigators and by other methods.

No doubt due to the limitations

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of the testing devices available in their laboratory the rates of corrosion observed were generally at a much lower level than those encountered in the field. As a matter of fact if corrosion in the field proceeded no faster than indicated by these data there really would not be much of a problem. Consequently, we are inclined to question the ultimate significance of the comparison among the different compositions of steel under testing conditions so much less severe than those responsible for considerable damage in the op-

erating wells. The more highly resistant materials like the nonferrous alloys and the high chromium steels are probably less sensitive to conditions and the data provided here are probably a reliable guide to their performance in service.

Field exposure has indicated that corrosion is most severe on surfaces that are kept clean by turbulence whereas in the laboratory tests it appeared that corrosion was greater under deposits of corrosion products. It would be of interest if a testing method—such as the use of a high velocity jet—could be devised that would permit comparisons of steels corroding at a maintained initially high rate by continual removal of corrosion products as fast as they were formed. In this connection it may be noted that in our Research Laboratory at Bayonne, N. J., we observed that steel was corroded at rates as high as 0.15 ipy during the first two hours of exposure to distilled water through which carbon dioxide (CO_2) was bubbled at 70° C. under a pressure of 35 psi. This rate was about 30 times higher than that reported by these investigators. In this test the specimens were moved at a low speed or about 15 rpm. Perhaps bubbling the CO_2 through the solution insured a more adequate supply of the corroding chemical than was achieved in the method used by the present investigators.

It is believed that in the wells the corrosive condensate exists in a state which results in contact of the metal with only a thin film or drops of condensate which may be in rapid motion. In the laboratory test the corrosive media were in the form of relatively large bodies of liquid in which the specimens were immersed. This difference might well have been significant with respect not only to the opportunity for secondary reactions with and between corrosion products but also as to the chance that an insoluble corrosion product would form on the corroding surface.

This difference in the condition of the electrolyte is also significant with respect to the possibility of galvanic effects. The data referring to the tests of galvanic corrosion of bare spots on nickel or copper plated steel are in line with what would be expected for these testing conditions involving a relatively large volume of electrolyte of good conductivity. However, in the field it is doubtful that a similar body of electrolyte ever would exist inside tubing. Consequently, the area of cathode likely to take part in any galvanic reaction will be restricted and the intensity of any galvanic effect similarly limited. This would apply also to dissimilar metal combinations other than those associated with metallic coatings. It may be noted also that the thickness of metal coating that would be used to provide the required protection would be such as not to be likely to be penetrated by accidental damage in handling or installation.

It is hoped that these investigators will continue to contribute to the solution of this problem and that they will extend their observations of effects of alloy composition to conditions where ordinary steel is corroded at much higher rates than in the tests covered by this paper.

Cathodic Protection of Steel in Sea Water With Magnesium Anodes*

*By R. A. Humble**

THE PROGRAM of research covered by this paper was designed to determine the feasibility of the use of magnesium anodes for the cathodic protection of steel in sea water. Its principal objectives were the selection of the most suitable magnesium alloy for this service with respect to solution potential, freedom from polarization, and current efficiency, together with a study of the minimum current requirements of the steel cathode under varying conditions of exposure. The results obtained to date may be conveniently divided into two parts; the first dealing with the anodic performance of various magnesium alloys, and the latter with those reactions which take place at the cathode.

Part I.—Anodic Performance of Magnesium in Sea Water

Experimental Procedure

A study has been made of the anodic performance of a group of five magnesium alloys in sea water

at the corrosion testing station at Kure Beach, N. C. The composition of these alloys is shown in Table I.

Standard 4 inch by 20 inch cast magnesium anodes were used in these tests, and were suspended in plastic frames, as shown in Figure 1, at a depth of approximately 4 feet below mean low tide. Twenty anodes of each metal composition were tested, sixteen of which were electrically coupled to the sheet steel piling walls of the test basin, while the remaining four served as uncoupled controls.

Calibrated 0.002-ohm shunts were installed in the anode-to-piling circuit. Multi-point Leeds and Northrup recording potentiometers were connected across these shunts to measure and record the current flow. A range of anodic current densities was obtained by installing fixed resistors, having values of from 0.05 to 2.0 ohms, in series with the current measuring shunt.

The magnesium anodes were weighed prior to immersion and again after cleaning in a 20 percent chromic acid solution at the completion of the tests, which are generally three months in duration.

Anodic Solution Potentials

Solution potentials of these anodes were determined at the beginning and end of the tests, using a saturated calomel reference electrode. The solution potentials were the same at end as at the beginning of the tests. The potentials observed are shown in Table II. These data show that the magnesium anodes are approximately 0.7 volts more anodic than steel which has been polarized to a protective potential of —0.78 volts (saturated calomel electrode). This is sufficiently high to insure an adequate flow of current for the polarization of the cathodic areas on the structure for which protection is desired. While a high solution potential is less essential in sea water applications than in high resistance environments, it does give added "throwing power." This permits grouping of anodes with a corresponding reduction in the number of anode installations.

Anode Polarization

Solution potentials of magnesium anodes are not adversely affected by time or the rate of current output; they provide a constant flow of current for a given medium and cathode potential. Anodic polarization may usually be attributed to the formation of a high resistance adherent film of corrosion products. Since the corrosion products of magnesium in sea water are nonadherent, little change in potential with either time

TABLE I
COMPOSITION OF MAGNESIUM ALLOYS

ALLOY DESIGNATION	Al	Cu	Fe	Ni	Mn	Zn
Cell Magnesium	< .01	< .01	.027	< .001	.10	.01
Dowmetal FS 1	2.6		.003	.005	< .001	.4	1.1
Dowmetal H	6.0	< .01	.009	< .001	.26	2.5
Dowmetal H-1	6.5	< .01	.001	< .001	.24	3.4
Dowmetal J-1	6.5	.005	.001	< .001	.23	.78

or current output was observed. In Figure 2 the potential of Dowmetal H-1 anodes are seen to approach a straight line when plotted against current output.

Current Efficiency

Although high solution potentials and freedom from polarization are essential for the satisfactory performance of galvanic anodes, their use may not be practical economically unless the consumption of metal per ampere-hour of current supplied is low. Theoretically 1000 ampere-hours may be recovered as useful current for each pound of magnesium expended. In practice, from 550 to 625 ampere-hours per pound are recovered for the H-1 alloy (the metal composition normally used in sea water installations), the balance being lost through local corrosion effects. The current recoveries for the five magnesium compositions tested are shown in Figure 3. The shape of these curves is characteristic of the anodic performance of magnesium; both the useful and the local corrosion currents increase with increas-

ALLOY DESIGNATION	SOLUTION POTENTIAL vs. SATURATED CALOMEL ELECTRODE.	
	OPEN CIRCUIT	CLOSED CIRCUIT.
Cell Magnesium	−1.63 volts	−1.56 volts
Dowmetal FS I	−1.54 volts	−1.42 volts
Dowmetal H	−1.51 volts	−1.46 volts
Dowmetal H-I	−1.51 volts	−1.47 volts.
Dowmetal J-I	−1.50 volts	−1.46 volts

ing current density, sharply at first and then approaching some limiting current efficiency.

Curves 1 to 6 (Figure 3) show the relative performance of the various alloys after three months' exposure. Dowmetal H-1 (6 percent Al, 3 percent Zn, 0.3 percent Mn, with low iron) gave the highest current recovery. These H-1 anodes, after sandblasting to remove any possible surface effects resulting from the chromic acid cleaning bath, were exposed for an additional three months. The current efficiencies obtained during this latter period are shown by Curve 1-A. The difference in current recovery between the first and second exposures (Curves 1 and 1-A) is attributed to the removal of an aluminum-rich chill skin from the surface of the anode during the first three months' exposure. The aluminum-rich metal is formed on the surface of the cast anodes by inverse segregation during cooling. Because it is cathodic to the magnesium alloy, its presence results in accelerated local corrosion characterized by a pitting type of attack and lower current efficiencies.

Once this chill skin has been removed, either by corrosion or, as is more probably the case, by under-cutting and spalling, a smoother corrosion pattern and correspondingly higher current recoveries are observed. The data shown in curve 1-A are therefore believed to be more representative of the current recoveries which will be realized when the anode is operated to exhaustion. A similar increase in current efficiency with time would be predicted for the other compositions tested with the exception of cell magnesium. Because cell magnesium contains no added aluminum, inverse segregation does not occur, and no increase in current efficiency with time would be anticipated.

Part II.—Current Requirements for the Cathodic Protection of Steel in Sea Water

Cathodic protection of steel in sea water poses a problem in that current requirements have been found to change rapidly with time after the application of a protective current. If current densities sufficiently high to effect immediate protection are applied, in a short time it will be found that the applied current is greatly in excess of the current actually required for protection. On the other hand, if current densities of the order of those required after equilibrium is established are applied initially, it is found that as much as several years may elapse

before complete control of corrosion is obtained. To the corrosion engineer this poses something of a dilemma so far as the selection of an appropriate current density and current sources of proper capacity is concerned. In general, two alternative methods of effecting protection are possible, and the major purpose of this report has been to investigate and evaluate these methods.

Cathodic protection may be effected by the application of some fixed current density which is too low to give immediate protection. At this selected current density corrosion generally continues at a steadily diminishing rate for from three to twelve months until protection is eventually achieved. An alternate method is to apply a high current density initially to obtain immediate protection. The current density is subsequently reduced to the lowest value which will maintain the protection so achieved. In sea water the latter method is believed to have three advantages, namely:

(1) Immediate protection is obtained.

(2) The high initial current densities precipitate a calcareous coating over the surface of the cathode which affords considerable protection to the underlying steel.[1] The presence of such a coating reduces the current density requirements for the maintenance of protection.

(3) The total current requirements are lower, based on an extended period of exposure.
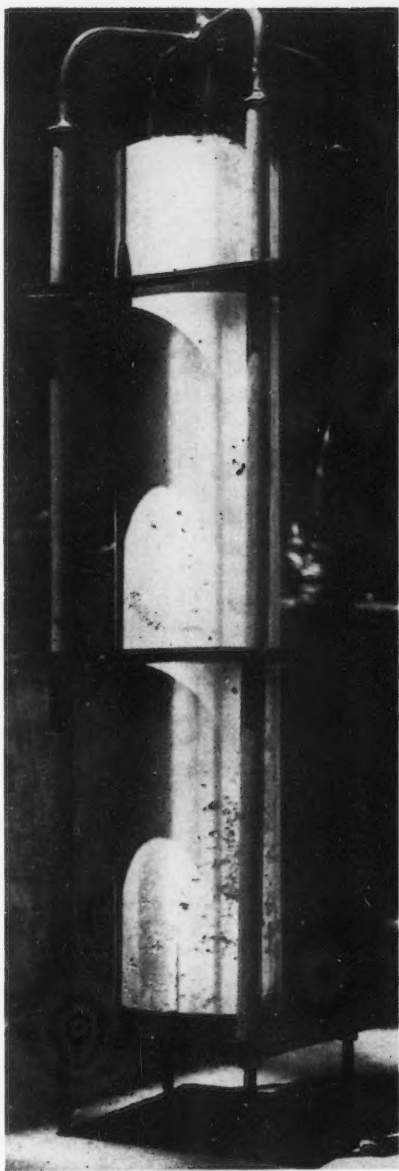
Figure 1—Plastic supporting frames for test anodes.
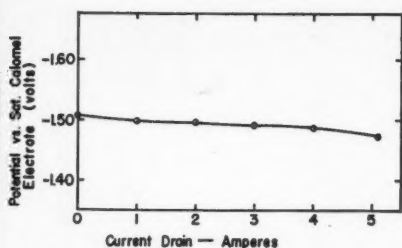
Figure 2—Potential versus current drain for Dowmetal H-1 anode in sea water.

Additional objectives were to determine the effect of rust films, velocity, and water temperature on the rate of corrosion in sea water and the current required for protection. Certain of these objectives have been attained and the result are herein reported.

Experimental Procedure

The cathodes used in these tests were 12 inch by 12 inch by ⅛ inch "killed" steel plates which were attached to channel iron racks, as is shown in Figure 4. The plates were

insulated from the supporting racks by bakelite washers and sleeves. The racks were suspended at a depth approximately 3 feet below mean low tide. The test plates were coupled to magnesium anodes through a current measuring shunt placed in series with a manually operated variable resistance, which was used to regulate the current flow to the desired value. Multipoint Leeds and Northrup recording potentiometers were connected across the calibrated shunts to measure and record the current flow.

The test plates were sandblasted and weighed prior to exposure. At the completion of the test the plates were cleaned by sandblasting, using low pressure air (40 pounds) and a worn nozzle, and their weight loss determined. It has been shown that such a cleaning procedure results in an average loss of two grams per plate, which has been applied as a correction factor in the data shown in Figures 5, 6 and 9.

Figure 3—Effect of current density on the current efficiency of magnesium anodes in sea water; performance curves for: (1) H-1, (2) FS-1, (3) H, (4) J-1, (5) cell magnesium, and (1A) H-1 on second exposure.
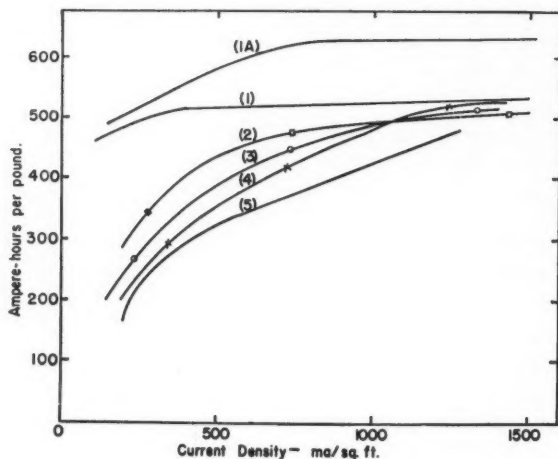
Figure 4—Mounting and suspension of test plates.

These tests were conducted under the conditions now prevailing at the test site, namely, sea water, which is saturated with respect to oxygen, having a salinity range of from 95 to 104 percent of normal and a temperature range of from 45 to 85° F. The velocity of the water was zero; its level rising and falling with the tides but with no definite flow.

The solution potentials of these plates with respect to current density and time were studied. For this purpose a saturated calomel reference electrode equipped with a long salt bridge was used. The tip of the salt bridge was bent at right angles so that it could be brought in intimate contact with the vertically suspended test plates and thus reduce to a minimum those errors resulting from IR drops through the sea water.

Current Requirements of Sandblasted Steel Plates

A group of 21 "killed" steel test plates were exposed in June, 1946. These were immediately coupled to magnesium anodes, three plates being operated at each of the following current densities: 0.0, 1.0, 2.0, 3.0, 5.0, 7.5 and 10 milliamperes per square foot.

One plate at each current density was removed after three and twelve-month exposures. The weight losses of these plates versus current density are shown in Figure 5. Little protection was achieved during the first three-month exposure, a considerable amount of corrosion occurring even at the highest current density of 10 MA/sq.ft. During the remaining nine-month exposure the degree of protection was roughly proportional to the applied current density, with almost complete protection being obtained at 10 MA/sq.ft.

The solution potentials of those plates operating at the higher current densities were found to be a reliable index of the degree of protection achieved. The initial potentials of this group of plates were approximately —0.75 volts. The potentials dropped steadily for the first 70 days, there being no significant difference
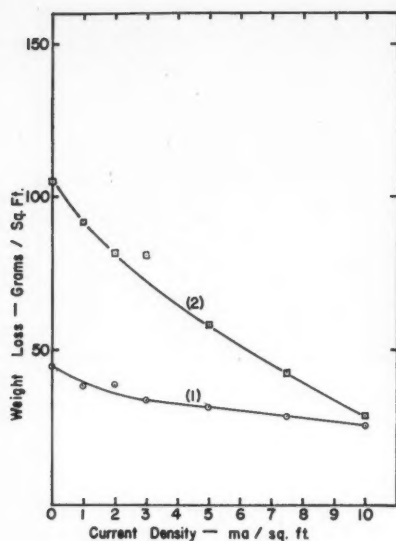
Figure 5—Weight loss versus applied current density for sand blasted plates for (1) three-month exposure, and (2) twelve-month exposure.
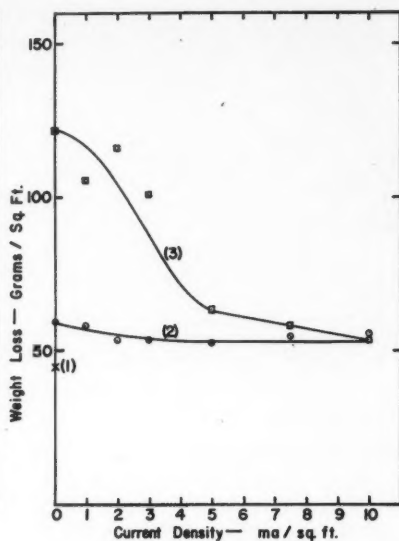
Figure 6—Weight loss versus current density for rusted plates after (1) three-month uncoupled exposure, (2) three-month coupled exposure, and (3) twelve-month coupled exposure.

between the plates at the various current densities. Shortly thereafter the potential of those plates operating at 10 MA/ sq.ft. began to rise sharply, reaching a protective potential of —0.78 volts after 104 days' exposure. Approximately 40 days later, a similar rise was noted for those plates operating at a current density of 7.5 MA/ sq.ft. The plates at 5.0 M.A./sq.ft. showed a slight increase in potential but did not reach the protective level. No significant difference was observed between those plates operating at 0.0, 1.0, 2.0 and 3.0 MA/sq.ft. These data indicate that a fixed current density in excess of 5.0 MA/sq.ft. and less than 7.5 MA/sq.ft. must be applied to protect bare steel in sea water.

The performance of these plates is believed to be indicative of the importance of time in determining the minimum current density required for protection. Initial measurements indicate that a current density in excess of 10 MA/sq.ft. is required to achieve protection, although protection is eventually effected at a current density of approximately 6 MA/sq. ft.

Current Requirements of Rusty Steel

The reduction in the amount of current required for protection with time is believed to result from the screening action of the corrosion products. The beneficial effect of the presence of such a rust coating is shown by the performance of a

TABLE III

COMPARISON OF WEIGHT LOSSES
OF SANDBLASTED AND RUSTED PLATES

CURRENT DENSITY MA/Sq. Ft.	SANDBLASTED PLATES WEIGHT LOSS Gms. / Sq. Ft.		RUSTED PLATES WEIGHT LOSS Gms. / Sq. Ft.		
	3 MOS. COUPLED EXPOSURE.	SUCCEEDING 9 MOS. COUPLED EXPOSURE.	3 MOS. UNCOUPLED EXPOSURE.	3 MOS. COUPLED EXPOSURE.	SUCCEEDING 9 MOS. COUPLED EXPOSURE.
0	44	60.7	45	14	63
3	34	46.5	45*	8.7	48.5
5	31.5	26.5	45*	7.0	11.5
7.5	28.5	14.0	45*	9.5	3.7
10	26	3	45*	10.0	0

*ASSUMED

second group of similar plates which were also exposed in June, 1946, but which were allowed to rust for a period of three months before any protective current was applied. Specimens were then removed to determine the weight loss during this unprotected period. The remaining plates were coupled to magnesium anodes and operated at the same fixed current densities as the sandblasted plates.

Plates were removed after three and twelve-month coupled exposures and the loss in weight determined. These data are shown in Figure 6. A comparison of the weight losses of the rusted and sandblasted plates for three and twelve-month coupled exposures is shown in Table III. While the total weight loss of the rusted plates is greater, due to the three-month period when no protective current was applied, their weight loss during the subsequent intervals of coupled exposure is sig-

nificantly lower than those of the sandblasted plates which were coupled at the time of exposure.

The difference in weight loss between the sandblasted and rusted plates is attributed to the presence of the coatings deposited by the corrosion process and the accompanying partial polarization of the local cathodic areas on the rusted plates at the time of coupling. When a freshly sandblasted plate is immersed in sea water corrosion appears at first to be general. Then relatively large areas become cathodic and are protected at the expense of the anodic areas which continue to corrode. Eventually certain cathodic areas become coated with a mixture of rust and calcareous material, which is precipitated by the electrolytic action of the local corrosion cells, while the remaining areas are covered with rust. This process is accompanied by a marked decrease in the corrosion rate as
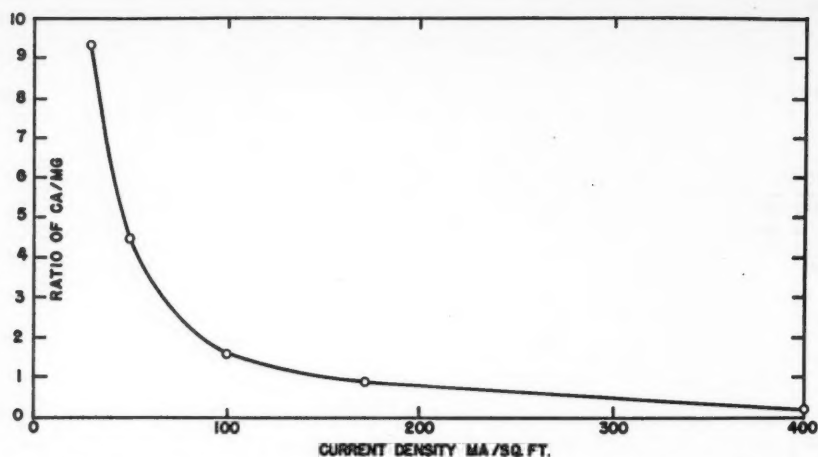
Figure 7—Composition of calcareous coatings formed in sea water; current density versus Ca/Mg ratio.

would be expected if the coatings serve to shield the underlying metal from the corrosive action of sea water.

For much the same reason the potentials of the rusted plates would be expected to respond more rapidly to a given applied current density. A significant increase in solution potential was observed for the rusted plates at 10 MA/sq. ft. after 25 days coupled exposure, and a protective potential was reached 72 days after coupling. The corresponding times for the sandblasted plates which were coupled at the time of exposure were 80 and 104 days. In contrast with the sandblasted plates, potential measurements showed that the rusted plates operating at a current density of 5.0 MA/sq. ft. reached a protective potential before the end of the test.

Factors Affecting the Formation and Composition of Calcareous Coatings

The most outstanding characteristic of sea water, insofar as corrosion is concerned, is the tendency to lay down calcareous de-

TABLE IV
ANALYSIS OF CALCAREOUS COATINGS

CURRENT DENSITY MA./SQ. FT.	50	100	172	400
% Na	.72	.85	.78	1.03
% Fe	3.78	3.46	2.60	2.12
% Si	.65	1.77	1.30	.41
% Cl	.44	.84	.76	.55
% CO$_3$	44.62	32.62	29.66	14.70
% Ca	28.91	20.88	17.54	6.73
% Mg	6.51	13.53	18.00	29.47
% Sr	.14	.06	.04	.006
% OH (Calculated)	8.37	18.18	23.35	38.52
Total	94.14	92.19	94.03	93.536
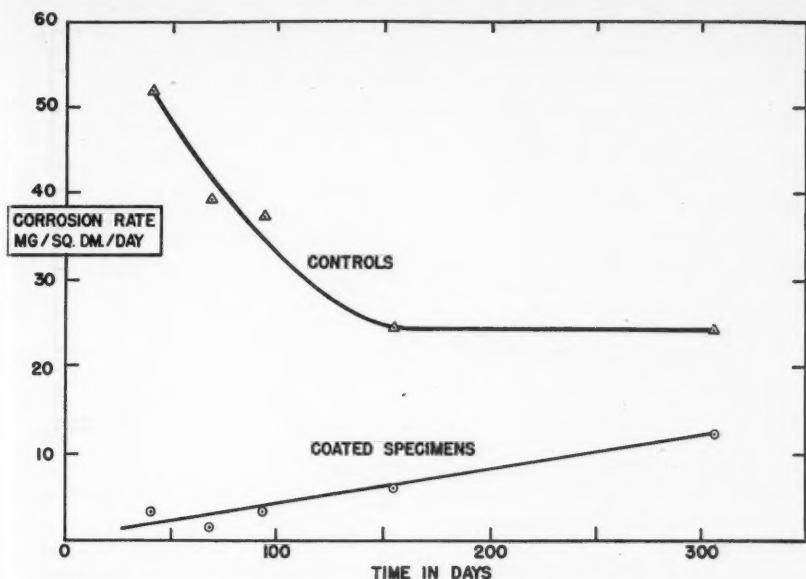
Figure 8—Corrosion rate versus time for coated specimens and controls in sea water.

posits on the cathodic areas. The polarization observed in sea water probably results from, and is invariably accompanied by, the deposition of such coatings. When a high current density (50 MA/sq. ft. or above) is initially applied to achieve immediate protection, the formation of rust can be prevented on sandblasted steel plates, and the entire surface is covered with a calcareous deposit. The calcareous film consists principally of calcium carborate ($CaCo_3$) and magnesium hydroxide ($Mg(OH)_2$), the ratio between the two being dependent upon the current density applied, the composition of the water, and the velocity or turbulence of the water at the surface of the cathode.

When cathodic protection is applied, hydrogen ions are discharged at the cathode with a resulting increase in the pH of the water film immediately adjacent to the cathode. It has been shown from solubility product considerations that with increasing pH calcium is first precipitated as $CaCO_3$, followed by strontium carbonate, ($SrCO_3$), magnesium carbonate ($MgCO_3$), and finally, $Mg(OH)_2$. It would therefore be expected that coatings formed at low current densities would be rich in calcium and those formed at high current densities would be rich in magnesium due to the higher concentration of magnesium in sea water. The changes in composition of such coatings with current density are shown in Table IV.

The ratio of calcium to magnesium at the various current

densities is shown in Figure 7. Coatings formed at the lower current densities are believed to be more permanent due to the lower solubility of $CaCO_3$ at the normal pH of sea water. The time required for formation of such coatings is roughly proportional to current density; at 50 MA/sq. ft. a satisfactory coating is obtained in five days. These coatings may be formed at current densities as low as 20 MA/sq. ft. under the semi-stagnant conditions prevailing at the test site. While no quantitative data is as yet available on the effect of velocity, it is believed that at a given current density, the pH of the water film at the cathode is reduced with increasing velocity. The formation of calcareous coatings would therefore become increasingly difficult as the water velocity is increased.

These precipitated coatings of calcareous material provide a consider-

TABLE V
CURRENT DENSITIES FOR CALCAREOUS COATED PLATES

NUMBER OF PLATES	SURFACE CONDITION	APPLIED CURRENT DENSITY MA/ SQ. FT.
3	BARE	0
3	COATED	0
3	"	1
3	"	2
3	"	3
3	"	5
3	"	7.5
3	"	10.0
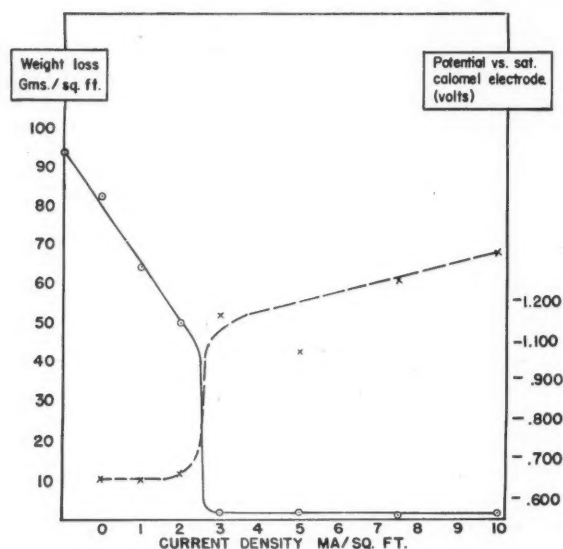
Figure 9—Weight loss and potential of coated plates versus applied current density after one-year exposure in sea water.

able degree of protection to steel in sea water. In Figure 8 a comparison is made of the corrosion rates of bare and coated steel plates. The plates in this test were coated by the application of a current density of 175 MA/sq.ft. for one day, after which no protective current was applied. Bare and coated plates were removed after one, two, three, five and ten-month exposures and the corrosion rates determined. The corrosion rate of the coated plate was found to be approximately half that of bare steel after a ten-month exposure.

The protective action of these coatings is believed to be threefold:

(1) It serves as a barrier to oxygen or other depolarizers.

(2) It increases the internal resistance of the local corrosion cells.

(3) The pH of the water film in immediate contact with the metal surface is increased above that of normal sea water.

Current Requirements of Coated Steel

In the presence of such a calcareous coating the current density required for protection is substantially reduced. This is shown by the corrosion rates of a third group of plates which were coated at an applied current density of 50 MA/sq. ft. for a period of five days. Current densities were subsequently reduced to the values shown in Table V.

Plates were removed after three, six, and twelve-month exposures and the corrosion rates determined. The weight losses of those plates removed after one year's exposure are shown in Figure 9. Protection was virtually complete at current densities of 2 to 3 MA/sq. ft. and above. Also shown in Figure 9 are the solution potentials of this group of plates at the time of removal. The sharp upward swing of the potential curve occurs at the same current density as the downward break in the corrosion rate curve. Such a correlation of potential with weight loss emphasizes the value of potential measurements in this type of corrosion study for determining when protection has been achieved.

The application of high initial current densities to rusted plates was originally intended to serve a dual purpose. It was believed that the rust would be electrolytically exfoliated, after which the exposed steel would be covered by a calcareous deposit. Light rust formed by continuous immersion, or heavy rust which has been exposed to the atmosphere, is readily removed by the application of current densities ranging from 50 to 400 MA/sq. ft. Heavy rust, typical of that formed after long periods of continuous immersion in sea water, is not readily removed even at current densities of 500 MA/sq. ft. and above. At these high current densities the calcareous material is precipitated in the pores of the rust; continued application of such current densities results in the rust being covered by a soft calcareous deposit with no appreciable exfoliation being observed.

The coatings produced by the deposition of calcareous material in the pores of the rust have been found to afford a degree of protection which is comparable to that observed for calcareous coatings on bare steel. A protective potential has

been maintained on rust-covered specimens at current densities of from 2 to 3 MA/sq. ft. after the application of 50 MA/sq. ft. for a five-day period to effect polarization.

Comparison of Current Requirements

These data show that while the continuous application of a fixed current density of approximately 6 MA/sq. ft. is required to achieve eventual protection for bare steel in sea water, protection effected by the application of a high initial current density can be maintained at 2 to 3 MA/sq. ft. A comparison of the number of ampere-hours required to protect one square foot of steel for one year by each of these methods is shown below:

(1) Constant Current

Ampere-hours

$$1 \times 365 \times 24 \times 0.006 = 52.56$$

(2) Initial Polarization

$$1 \times 5 \times 24 \times 0.05 \quad = \quad 6.0$$
$$1 \times 360 \times 24 \times 0.003 = 25.92$$

TOTAL   31.92

Ampere-hours saved   = 20.64

The use of a high current density to provide initial polarization is thus seen to result in a savings in ampere-hours required of approximately 40 percent. The additional expense of the polarizing or priming installation can therefore be justified both by the prevention of initial corrosion and by the savings in current which permits a corresponding reduction in the size of the permanent anode installation.

Summary

Magnesium anodes are shown to perform satisfactorily when used for the cathodic protection of steel in sea water. Solution potentials of — 1.5 volts (versus saturated calomel electrode) are observed; these are practically independent of time and the magnitude of the current flow. Recoveries of 500 to 600 ampere-hours per pound of metal consumed are realized.

Sandblasted steel is shown to require in excess of 10 MA/sq. ft. for initial prottection, although protection may be eventually achieved by a fixed current density of approximately 6 MA/sq. ft. Rusted steel can be protected at a slightly lower current density.

Protection can be effected at current densities as low as 3 MA/sq. ft. by the application of a high initial current density (50 MA/sq. ft.) to achieve immediate polarization. The high initial current density stabilizes the current requirements with respect to time. This permits the use of a considerably smaller permanent anode installation with a savings in current of approximately 40 percent.

Acknowledgement

Reference

1. G. C. Cox, U. S. Patents Nos. 2,200,469 (1940) and 2,417,064 (1947). British Patent No. 540,487 (1941).
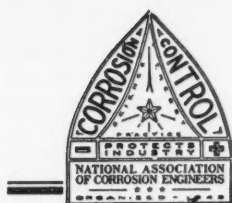
*Proceeding with a plan of continual improvement for the benefit of its readers,
CORROSION introduces this new column. Topic of the Month will be a regular feature
prepared by the various Staff Correspondents of the magazine, and through the diversity of
their specialized knowledge in their respective fields, provide a cross-section of industrial
corrosion problems and their control or mitigation. Additional features have been planned,
including a Questions and Answers Department, and all will be part of the new bigger
and better CORROSION which will be introduced in January 1949.*

TEST OF NICKEL PLATED A.P.I. TYPE JOINT IN FLOW LINE
OF CORROSIVE DISTILLATE WELL

By B. B. Morton★

A S A CONTINUATION of a study of the resistance of nickel plated tubing to the corrosives of a distillate well (as reported in CORROSION, November, 1947, Vol. 3, No. 11, page 592) a T & C Joint of 2½-inch A.P.I., External Upset, Oil Well Tubing was installed in the flow line of the Grey Cox No. 1 well of the Cotton Valley Operators Association, Cotton Valley, La., during the Fall of 1947.

The T & C joint had two distinctive features that made it of particular interest. One feature was that

the threading of the coupling, also of the pipe, as well as the interior of the pipe were all nickel plated with about 6-8 mils of nickel. The other feature was that a part of the nickel had been removed from the chamfer of the pipe prior to its assembly into the coupling. The presence of this exposed steel area at the chamfer and first lead thread of the pipe, surrounded as it was by nickel plating offered a location where severe galvanic effects could be anticipated. The location of the joint in a horizontal line would lead to a pool of water forming in the coupling between the ends of the pipe, and thus would provide the electro-

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★ Development & Research Division, The International Nickel Co., New York, N. Y.
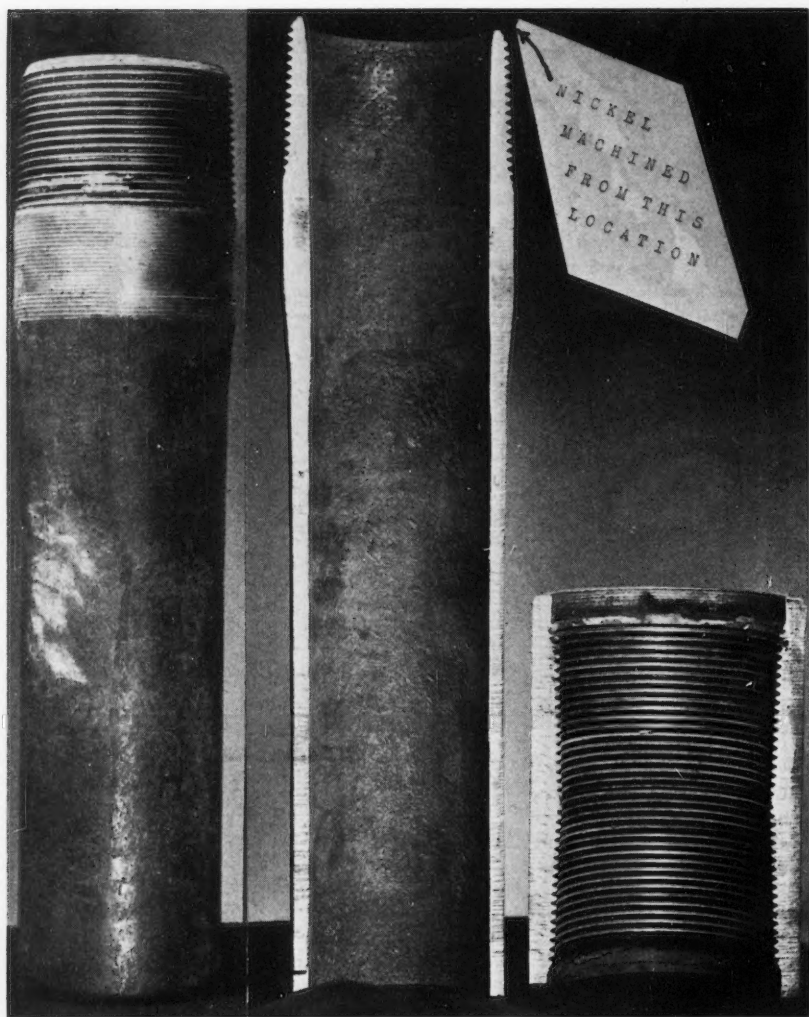
Appearance of nickel plated 2½ inch API type joint after exposure of about nine months in the flow line of a condensate well. Coupling and tubing plated on inside and over threads with 6-8 mils of nickel. Nickel removed at location indicated.

lyte that would permit galvanic corrosion. Serious galvanic corrosion was anticipated by the writer and the attention of the engineers at Cotton Valley was called to the condition of the joint for fear that the corrosion would proceed through the threads and might lead to a "washout" in the coupling. The authorities at Cotton Valley, placing confidence in the choke in their line, preferred to allow the piece to remain as a part of the general study of the corrosion by the distillate wells. This decision has proved to be sound and has provided some interesting information.

After nine months exposure, the coupling was removed (see Figure 1) and sectioned with the following results:

1) The nickel plating on the threads of the pipe and the coupling, also within the pipe, had suffered no observable corrosion or pitting. The 2-inch nickel plated line pipe, in which the coupling was installed, had suffered no marked corrosion or pitting of the nickel plate. It had been in test for about two years.

2) The exposed surface of the steel at the chamfer and first lead thread of the pipe of the joint suffered marked corrosion but not of the intensity that might be anticipated from the galvanic couple that existed between the relatively small area of the steel and the relatively large area of the nickel plating. In fact, it might be considered that the corrosion of the steel is normal when considering other steel parts exposed in this flow line.

The writer is rather of the opinion that galvanic corrosion did not exist or was quickly eliminated as a major factor in corrosion of the exposed steel. The reason is not clear, but fits into the general picture that galvanic effects are often missing in the case of corrosion in petroleum wells. For instance, nickel plated sucker rods damaged by wear against the wall of the tubing have not shown the intensity of corrosion that might be expected if galvanic effects were prominent. Reports also have been received of steel couples in bronze sucker rod strings that have not been unusually attacked. In these cases the absence of oxygen was concluded to be a factor in retarding galvanic corrosion. In the case of the joint under discussion, the presence of carbon dioxide in the gases from this well might be expected to compensate for the absence of oxygen, however, the galvanic effects were not marked as has been stated.

The general conclusion that has been drawn from this present study is that the breaking through of a nickel plate coating of a tubing in a condensate well of the type studied will not result in as serious attack upon the steel as has been previously anticipated. It is also considered that a lighter coating of nickel than used in the tube, will be adequate to protect the threads of the pipe. This will facilitate the preparation of the ends of oil well tubing that is to be nickel plated.

The couple and the tubing described herein was plated by Bart Industries, Belleville, N. J., and was installed by Pittsburgh Steel Co., Pittsburgh, Pa. The Management of the Cotton Valley Operators Association is again thanked for making this test possible.
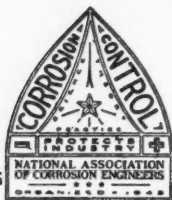
NACE News

ASSOCIATION ACTIVITIES

The NACE Executive Committee met June 2 at the Bame Hotel in Carolina Beach, N. C. O. C. Mudd, Treasurer, and Ivy M. Parker, Chairman of the Publication Committee, were present as visitors. The group took advantage of the opportunity to inspect the Kure Beach Corrosion Test Station, and to set in on four informal discussion sections. These sections took up the following topics as related to corrosion in sea water: (1) Ferrous Alloys, (2) Copper and Nickel Steels, (3) Light Metals and Alloys, and (4) Miscellaneous. The discussions were very interesting and informative to the approximately 200 persons in attendance.

Wm. D. Shaw, head of the Corrosion Department, Research Laboratories, National Lead Company, Brooklyn, N. Y., advises that an effort is being made to form a New York Section. According to Mr. Shaw, preliminary meetings were held May 19 and June 16, to work out details and perfect organization before submitting a formal request for recognition as a Section to the North Central Region Chairman.

Representatives of the Atlanta Gas & Light Co., American Telephone & Telegraph Co., Atlantic Steel Co., Plantation Pipe Line Co. and the Shell Pipe Line Corp., held a luncheon meeting May 31 in Atlanta, Ga., for the purpose of discussing corrosion problems peculiar in the South East Region. Principle topic was that concerning the effect of lightning upon buried cables. Though a few direct hits have been recorded during the many and severe electrical storms common to the area, the greatest trouble is caused by induced current flow, which tends to rupture cables at points of low soil resistance. During the discussion it developed that cathodic protection is the likely answer to the problem, with galvanic anodes being utilized to provide a drainage for these surge currents. Another problem peculiar to the area which came in for discussion was that concerning the difficulty in applying adequate cathodic protection, due to geological formation. O. C. Mudd, Shell Pipe Line Corp., Houston, Texas, and Ivy M. Parker, Plantation Pipe Line Co., Atlanta, Ga., were among the 14 members of NACE who took active part in the discussions.

4

GENERAL INTEREST

Leading industrialists were prominent in activities of the American Society of Mechanical Engineers, held May 30 through June 5 at Hotel Schroeder, Milwaukee, Wis. Coupled with this National meeting, which drew an estimated 2000 visitors, was an extensive exhibition of industrial products. Also keyed into the program was a series of plant tours. Twenty-eight technical sessions were held during which more than 75 papers were presented.

Increasing recognition by hygienists and engineers that engineering principles can be used to advantage in exhaust system ventilation to remove toxic fumes and gases, has led to re-organization of the Sectional Committee on Safety Code for Industrial Exhaust and Ventilation. The committee, organized under the procedure of the American Standards Association, is sponsored by the International Association of Industrial Accident Boards and Commissions. Theodore Hatch, Industrial Hygiene Foundation, is chairman of the reorganized committee. Work of the committee is being planned around specific operations for which exhaust ventilation is needed rather than for the development of specifications by industries, or for the equipment. Ten operations have been agreed upon as the basis for future work. They include mechanical cutting and abrading; surface coating; open tank operations; solid materials handling; fuel burning-exhaust gas producing operations; molten materials handling; welding, burning and soldering; fibre handling; volatile and gaseous material handling; and chemical process operations. This list was compiled by a subcommittee working under the leadership of Arthur Stern, New York Dept. of Labor, who represents the American Society of Mechanical Engineers on the Committee. Sub-committees have already been appointed to start work on specifications for surface coating operations, open tank operations and handling of solid materials.

PERSONALS

The Dow Chemical Company's Magnesium Division has extended its system of individual sales managers by appointing **J. C. H. Stearns** manager of ingot sales, **G. W. De Kuiper** manager of wrought product sales, and **T. H. Caldwell, Jr.,** manager of die casting sales. Newly named manager of the Eastern Area for magnesium sales is **E. H. Killheffer,** now located in Dow's New York office, and formerly Boston territory magnesium sales manager. **J. C. Mathes,** former director of technical service, has been named Western sales manager, and **J. C. McDonald** has assumed responsibility for the technical service department.

C. I. Hayes, Inc., 75 Baker St., Providence, R. I., appointed **Leonard J. Edwards,** with headquarters at the same address, as New England sales representative for the Company's line of industrial electrical heat treating and hardening furnaces. Mr. Edwards was formerly sales manager for General Alloys Co. of Boston, Mass.

William G. Mengel, formerly of York, Pa., has joined the Napko Paint and Varnish Works, Houston, Texas. Mr. Mengel has had 20 years experience in the industrial coatings field, nine of them as technical service representative with Roxalin Flexible Finishes, New Jersey. His experience covers a complete diversification of product finishing, including fleet finishes, aircraft, ice making and air conditioning equipment, as well as specialized industrial maintenance work. He will head Napko's new industrial technical service department.

Midwest Research Institute announced appointment of six new technical staff members. Following are additions to the Engineering Mechanics Department: **Herbert Arenson,** mechanical engineer formerly with North American Aviation and Panhandle Eastern Pipe Line Co.; **Malcolm R. Easterday,** previously associated with Electronics Development Laboratories of Railway Radiotelephone Co., Kenman Engineering Co., and Aieron Manufacturing Co.; **Wallace Merit Yocum,** formerly with Trans World Airlines; **Lawrence A. Platt,** formerly with Keystone Trailer and Equipment Co. and Butler Manufacturing Co. The following are new members of the Agricultural and Organic Chemistry Department: **Miss Dorothy B. Powers,** formerly with E. I. duPont de Nemours & Co., Inc.; and **Harold M. Branine,** who recently received his B.S. in chemical engineering from the University of Kansas.

Greta Scott, specialist in spectroscopy and X-ray diffraction work, has joined the staff of Hall Laboratories, Pittsburgh, Pa., chemical engineering consultants. Miss Scott was in charge of radiography laboratory of the American Radiator and Standard Sanitary Corp. from 1943 to 1945 when that firm was engaged in the manufacture of cast armor parts for military tanks. In 1945 she joined the Natural Science staff at the University of Pittsburgh, serving as research assistant in X-ray work until acceptance of the post at Hall Laboratories.

William J. Youden, internationally known mathematical statistician and chemist, has been appointed to the staff of the National Bureau of Standards as Assistant Chief of the Statistical Engineering Section. Youden has been for many years with the Boyce Thompson Institute for Plant Research. At the Bureau of Standards, Youden will work on the statistical and mathematical design of major experiments in physics, chemistry, and engineering and will act as special adviser on these problems to the Director.

Ivy M. Parker, Editor of CORROSION, and Chairman of the NACE Publication Committee, was one of the instructors at the North Carolina Annual Water Workers School, held at Chapel Hill, N. C., June 7-11. A great deal of interest was shown in the corrosion classes.

To direct their rapidly expanding Amercoat Division (protective coatings), the American Pipe and Construction Co. of Los Angeles has appointed **Alan E. Turner** vice president and general manager. Mr. Turner previously was vice president of Barrington Associates, Inc., New York management consultants. For more than six years previous to his association with Barrington, he was Executive Vice President of the H. B. Davis Company, Baltimore paint manufacturers, and of their subsidiary company, John W. Masury & Son, Inc.

NEW PRODUCTS, MATERIALS AND SERVICES
—Literature—

Beacon Rust Proofing Co., 19 West 31st St., New York, N. Y., is now marketing a water soluble cutting oil under the trade name, Ferrox, which they claim will eliminate further rust prevention treatment of tools, materials and machinery. From a formula extensively used in Germany before the war, the product is said to go farther in application where cutting oil is required. For most metals, it is used one part to 49 parts of clear water. For use on cast iron and malleable iron, the ratio of mixture is one part in 33, and in operations which call for threading or polishing the ratio is one part in 35.

In refutation of the old adage that a doctor never takes his own prescriptions, Shellmar Products Corp., Mount Vernon, Ohio, has recently made shipments of machinery packaged in accordance with the Method 11 procedure established during the war. This packaging method involves the use of a "water vapor protective barrier" which completely encloses the machinery and its dunnage. This barrier prevents the ingress of moisture which might cause corrosion on highly machined and delicate parts of mechanical equipment. To account for the moisture trapped inside the barrier, bags of silica gel, a dessicant, are spotted throughout the interior to absorb trapped moisture. By use of this dehydration packaging, machinery can be shipped free from grease or preservative compounds without fear of corrosion. Only regular working oil is applied and when unpacked, such equipment is ready for use without the expensive and time-consuming process of degreasing. Shellmar is engineering and furnishing such moisture vapor barriers to many builders and shippers of large

and small precision machines and assemblies.

A new Glass Section has been added to the laboratory facilities of Sam Tour & Co., Inc., engineers, metallurgists, consultants. Due to the increase in the use of glass, particularly for packaging consumer items, this new section will specialize in glass failures in an effort to contribute to the improvement of glass for containers and industrial applications. This new Glass Section, set up with the most improved glass testing equipment, will be located in the company's building at 44 Trinity Place, New York City.

Information concerning "Mollerizing" a method of impregnating iron products with aluminum, which was developed by Goran Moller, and used by the Aluminiseringsverken in Sweden in impregnating a wide range of steel and iron products for the past ten years, is available from Linden & Co., 901 Westbourne Drive, Los Angeles, Calif. The aluminum impregnation of steel and iron products such as sheet, wire, pipe, castings, forgings, and fabricated parts is accomplished by this method. The impregnation is claimed not only a protection against rust, but also a protection against the action of many acids, fumes, and corrosive atmospheres. In addition, the electrical and heat transfer qualities are said to be greatly improved.

The aluminum impregnation is easy to accomplish and is inexpensive. This method requires very little equipment, and uses a standard electric salt-bath furnace. The base metal is first degreased, descaled, thoroughly cleaned, and then lowered into an electric salt-bath furnace containing principally barium chloride on which is floated a bath of pure aluminum. When the metal being treated has been raised to the heat of the salt, 1600° F. to 2000° F., it is then removed through the aluminum.

As a result of this impregnation, the following is said to occur: First, the aluminum enters the pores of the steel and becomes an integral part of the steel, thereby forming an iron-aluminum alloy, which when quenched may have a hardness as high as 550 Vickers Brinell in addition to being corrosion resistant. Second, an exterior layer is deposited, which has all the corrosion-resistant properties of pure aluminum. The penetration of the aluminum into the base metal and the thickness of the impregnation is a matter of time and temperature and can be controlled to obtain the desired impregnation of the metal being processed. The base metal passes directly from the liquid barium chloride through the aluminum bath, and is thus prevented from oxidizing. The surface of the aluminum bath is prevented from oxidizing by the salt vapors which form a protective blanket over it. Additional information can be secured from Linden & Co., who is now issuing licenses for the use of this method in the United States and Canada.

Two new metal cleaners, said to be effective individually or in combination for cleaning a wide variety of metals and alloys, have been announced by Calgon, Inc., Pittsburgh, following a long period of laboratory and field research and testing.

The announcement marks official entry of this well-known chemical manufacturer into the metal cleaner field, with products specifically developed for this purpose, although the company's water-conditioning materials are used extensively in industrial cleaning work in connection with the application of other Calgon products.

Calgon Metal Cleaner No. 21 is described as a dry granular alkaline detergent for spray-cleaning in metal washing machines. In addition, it has proved effective when used in combination with the new Calgon Emulsion Cleaner, for immersion cleaning in dip tanks and for heavy-duty spray cleaning.

Calgon Emulsion Cleaner is described as a white, creamy emulsion of an organic solvent in a relatively small amount of water. It readily disperses when added to the cleaning bath. It is especially recommended for use in combined solution with Calgon Metal Cleaner No. 21 for immersion cleaning or especially difficult spray-cleaning. This mixture or combination of the two cleaners is said to provide the advantages of an alkaline cleaner with those of an organic solvent.

An abundance of information on the corrosion resistant properties of several common alloys to over 140 industrial chemical agents may be found in the Harper Computer of Corrosion Resistance, which has been prepared by the H. M. Harper Co., 2620 Fletcher St., Chicago 18, Ill. Of interest to corrosion engineers is the Analyses Chart of Corrosion Resisting Steels distributed by the Globe Steel Tubes Co., 4010 W. Burnham St., Milwaukee 4, Wis. Data are given for 467 stainless steels, produced by 17 leading companies of the industry.

Following introduction of Flagg-Flow, the first threadless malleable iron fitting, Stanley G. Flagg & Co., Inc., Philadelphia, has matched this development by applying the same principle in IPS brass and copper pipe or tubing, with Flagg-Flow bronze fittings. The new Flagg-Flow line in bronze gives to pipe fabricators a freedom of choice between ferrous and non-ferrous piping. The fittings are applicable for 150 pound working steam pressure lines at 450° F., or 300 pound non-shock cold water, oil, or gas lines. Applications of Flagg-Flow bronze fittings range from domestic use on hot and cold water lines, steam piping, radiant heating, and fuel oil piping,

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- *The fourth issue of the DIRECTORY OF THE AMERICAN COORDINATING COMMITTEE ON CORROSION, published in October, 1947, is now available through the Central Office of the National Association of Corrosion Engineers, 905 Southern Standard Bldg., Houston 2, Texas. The Directory, which occupies 62 6x9-inch printed pages in heavy paper binding, lists the names, addresses and fields of special endeavor of the principal corrosion workers in the United States and Canada. There is a cross-index system so arranged that an individual looking for someone who is a specialist in a particular phase of corrosion may readily find the information. The Directory consists of four parts: Section I, a subject index; Section II, an alphabetical index of individuals including addresses; Section III, an alphabetical index of organizations and companies, and Section IV, a numerical serial number listing of individuals. Section I is an alphabetical listing of corrosion subjects, under each of which are given the reference numbers to authors (listed in Section IV) who have contributed to each of the subjects listed. Also, each corrosion subject is given a marginal reference number that is used to indicate the corrosion subject on which each individual (listed in Section II) has contributed. Although the Directory was compiled and published by the American Coordinating Committee on Corrosion, through cooperative arrangements made between the ACCC and NACE, it is being offered for sale by the National Association of Corrosion Engineers at $2.00 per copy, the price having been determined by the ACCC.*

to industrial use on meter and instrument lines, lubricating oil piping, gas and air piping, boiler feed lines, hydraulic systems of not over 300 pounds, and in process piping where brass, copper pipe or tubing is applicable. Bronze threadless fittings can also be used in air, oil, and water systems in the transportation field, especially where vibration and inaccessibility make screwed piping inadvisable. Additional information on these bronze fittings may be obtained from the Flagg Co., 1421 Chestnut Street, Philadelphia 2, Pa.

Literature describing the salient features of the Electronic Caliper is available by writing the Gauge Division, Brady Motors, Inc., 400 Main St., Waltham, Mass. A new precision instrument into which have gone much time, effort, and money in development, the Electronic Caliper is a non-destructive precision device for measuring of corrosion and wall thickness. It is capable of measuring thickness of steel, copper, aluminum, brass, lead and grades of cast iron or any other electrical conducting material on boiler drums, process vessels, steam rolls, pipelines, tanks and containers, ship hulls, digestors, stills, water wells and tubes. It is claimed that the intrument is not affected by the degree of corrosion, pitting or scale formation on opposite surface, and accurately detects and measures lamination, if present. It operates either from 115 volts, 50 or 60 cycles power or its own self-contained 6-volt battery system. The standard instrument has an accuracy of 2 percent from one-eighth inch to three-quarters inch of the actual thickness. The range can be extended to 2¼ inches.

When the Petroleum Industry War Council was dissolved, W. R. Boyd, Jr., as Trustee and Liquidation Agent, entrusted to Shell Pipe Line Corporation and L. L. Ridgeway Company respectively the tasks of keeping up-to-date and printing the two U. S. Pipe Line Maps underwritten by the Council. With data furnished by line owners, the map covering Central United States has been revised by Shell as of May 1, 1948. Interesting newer lines added or concisely located are Magnolia 20″ Corsicana-Patoka line, Basin 20″-22″-24″ Jal-Cushing line, Ozark 22″ Cushing-Wood River-Patoka line, Wyco 8″ Casper-Denver products line, Sinclair 10″-8″ Houston-Wood River products line, Magnolia 12″ Beaumont-Hearne products line, Texas 10″-8″ Hearne-Dallas-Fort Worth, and 8″-6″ Hearne-Austin-San Marcos products line, Standish converting Mex-Tex line to crude oil service, and various shorter extensions. Prints of the revised Central United States map can be obtained direct from L. L. Ridgeway Co., 615 Caroline St., Houston, Texas. The map covering Eastern United States is now being brought up to date.

A new booklet, "66 Practical Ideas for Metal Problems in Electrical Products," has just been published by The International Nickel Company, Inc. It lists almost 100 service stories showing how electrical manufacturers have used high nickel alloys to overcome corrosion, heat, vibration fatigue, wear and other performance hazards. Thirty - six pages long, the booklet covers special operational problems such as high temperature, corrosion, formability, abrasion, fatigue strength, magnetostriction, and many others commonly confronting the electrical engineer and designer. It is illustrated by nearly 100 photographs. To get a copy, write The International Nickel Company, Inc., 67 Wall Street, New York 5, N. Y.

NEW NACE MEMBERS

Following is an alphabetical list of members added since publication of January Directory

A

ADKINS, J. L.
The Peoples Gas Light & Coke Co., 122 S. Michigan, Ave., Chicago, Ill.

AKER, LEWIS P.
Louisville Gas & Electric Co. 311 W. Chestnut St., Louisville, Ky.

ANDERSON, ALBERT A.
Standard Oil Co. (Ind.) Whiting Research Labs. Whiting, Ind.

ANDREWS, ALVIN G.
Michigan Bell Telephone Co. 1365 Cass Ave., Detroit, Mich.

AXELRAD, B. A.
Freeport Sulphur Co., Freeport, Tex.

B

BANNEN, JOHN
Carbide & Carbon Chemicals Corp., 437 McCorkle St., South Charleston, W. Va.

BARNES, R. Y.
Aluminum Co. of America 2210 Harvard Ave., Cleveland, Ohio.

BECK, WALTER
Lehigh University, Bethlehem, Pa.

BECKER, W. D.
Burns & Roe, Inc., 233 Broadway, New York, N.Y.

BELL, JAMES S.
Liquid Plastics Co. of Calif. 640 Broad Ave., Wilmington, Calif.

BERG, O. E.
Bethlehem Steel Co., 701 Third St., Bethlehem, Pa.

BETHON, HENRY E.
Bureau of Ships, Navy Dept. 17th & Constitution Ave., N. W., Washington, D. C.

BIONDOLILLO, SANDO
Bell Aircraft Corp., Niagara Falls Blvd., Niagara Falls, N. Y.

BITTLE, FRANK D.
Louisiana Polytechnic Institute, Ruston, La.

BLACK, CHARLES A.
Black Laboratories, Inc. 968 S. Oak St., Gainesville, Fla.

BLACK, RALPH P., JR.
Aluminum Co. of America, Power & Light Bldg., Kansas City, Mo.

BLACKHURST, A. O.
Consulting Chemist, Port Dover, Ontaria, Canada.

BLAKE, J. A.
Electric Steel Foundry Co., 4600 Pacific Blvd., Los Angeles, Calif.

BOCK, MORRIS
Sun Oil Co., 1369 N. Zangs, Dallas, Tex.

BORLAND, WILLIAM K.
Plantation Pipe Line Co., P. O. Box 1743, Atlanta, Ga.

BOST, ARMON H.
Midwestern Engine & Equipment Co., Inc., 105 N. Boulder, Tulsa, Okla.

BOWMAN, MACK M.
Colombian Petroleum Co., Apartado 100, Cucuta, Colombia, S. A.

BRADY, HUGH A.
Gulf Refining Co., Tulsa Pipe Line Div., First National Bank Bldg., Tulsa, Okla.

BREMER, CLARENCE
Oakite Products, Inc., 22 Thames St., New York, N. Y.

BRESHEARS, F. S.
Great Southern Supply Co., Inc., 2120 S. Wayside Dr., Houston, Tex.

BRIGGS, W. R.
W. A. Briggs Bitumen Co., 3303 Richmond St., Philadelphia, Pa.

BROWN, HUGH E.
The W. S. Tyler Co., 3615 Superior Ave., Cleveland, Ohio.

BROWNING, R. T.
Electro Rust-Proofing Corp., 1 Main St., Belleville, N. J.

BROYLES, WAYNE E.
Brance-Krachy Co., Inc. P. O. Box 1724, Houston, Tex.

BUELL, NORMAN S.
California Packing Corp., 240 Front St., San Francisco, Calif.

BURD, HARRY G.
Anaconda Wire & Cable Co., Hastings-On-Hudson, N. Y.

C

CALLAHAN, MELVIN C.
Gulf Refining Co., Tulsa Pipe Line Div., First National Bank Bldg. Tulsa, Okla.

CARTER, BEN F.
Union Producing Co., P. O. Box 1407, Shreveport, La.

CAYFORD, JAMES M.
Glascote Products, Inc., 20900 St. Clair Ave., Cleveland, Ohio.

CHANDLER, JOHN W.
Nukem Products Corp., Buffalo, N. Y.

CHERRY, RAY
Monsanto Chemical Co., Engineering Dept., Texas City, Tex.

CHESNUTT, N. P.
Southern Union Gas Co., 1104 Burt Bldg., Dallas, Tex.

CLARKE, B. C.
Pacific Metals Co., Ltd., 1400 S. Alameda St., Los Angeles, Calif.

CLAWSON, C. H.
Union Producing Co., United Gas Bldg., Shreveport, La.

COBBETT, C. D.
Hill, Hubbell & Co., Div. General Paint Corp., 3091 Mayfield Rd., Cleveland, Ohio.

COGHILL, H. T.
Ampco Metal, Inc., 2400 W. Madison St., Chicago, Ill.

COLE, RALPH R.
Allied Engineers, Inc., Fort Worth National Bank Bldg., Fort Worth, Tex.

COLLORA, NICHOLAS A.
Commercial Solvents Corp., 1331 South First, Terre Haute, Ind.

CONNELL, MRS. R. W.
Chemical Engineering Co., P. O. Box 1076, Dallas, Tex.

COONS, ANSEL L.
Hdqs. Fourth Army, Engr. Section, Fort Sam Houston, Tex.

CORWIN, GERALD A.
Ludwig Wilson Co., 112 S. Franklin St., Chicago, Ill.

11

COURT, W. F.
Shell Oil Co., Inc.,
50 W. 50th St.,
New York, N. Y.

COWART, B. C.
The Barrett Div., Allied
Chemical & Dye Corp.,
40 Rector St.,
New York, N. Y.

COX, GEORGE C.
Consulting Engineer,
3711 Washington Ave., S.E.,
Charleston, W. Va.

COX, GILBERT L.
The International Nickel Co.,
Inc.,
45 Exchange,
Rochester, N. Y.

COX, R. F.
Texas Eastern Transmission
Corp.,
P. O. Drawer 352,
North Little Rock, Ark.

CRAIN, GEORGE L.
Interstate Oil Pipe Line Co.,
P. O. Box 1107,
Shreveport, La.

D

DAVIS, C. R.
The Montana Power Co.,
40 E. Broadway,
Butte, Mont.

DAVIS, GEORGE W.
Pacific Metals Co., Ltd.,
3100 19th St.,
San Francisco, Calif.

DEACON, W. T.
Solvents & Plastics Co.,
8032 Forsythe Blvd.,
St. Louis, Mo.

DEBENPORT, H. R.
Foshee Electric Co.,
207 S. Main,
Fort Worth, Tex.

DEGNAN, THOMAS F.
E. I. du Pont de Nemours
& Co.,
Chambers Works,
Penns Grove, N. J.

DEWEY, EARL K., JR.
Continental Oil Co.,
P. O. Box 1267,
Ponca City, Okla.

DIETSCH, F. F.
Reynolds Metals Co.,
Aluminum Division,
1004 Baltimore,
Kansas City, Mo.

DOBSON, PAUL A.
D. W. Haering & Co., Inc.,
1001 N. Howard St.,
Glendale, Calif.

DONATI, ENRICO
Dalmine, S.p.A.,
Dalmine,
Bergamo, Italy.

DOREMUS, GORDON L.
Cathodic Protection Service,
Niels Esperson Bldg.,
Houston, Tex.

DRAGICS, EARL V.
Owens-Corning Fiberglas
Corp.,
M & M Bldg.,
Houston, Tex.

DUNASKY, C. F.
The Harshaw Chemical Co.,
1945 East 97th St.,
Cleveland, Ohio.

E

EILERTS, C. KENNETH
U. S. Department of Interior,
Bureau of Mines,
Bartlesville, Okla.

ELDRED, NORMAN O.
Bart Manufacturing Co., Inc.,
227 Main,
Belleville, N. J.

ENGEMOEN, R. J.
C. Harold Corrosion Co.,
P. O. Box 644,
Houston, Tex.

ENGLISH, E. ROWLAND
H. C. Price Co.,
P. O. Box 6120,
Philadelphia, Pa.

ENGLISH, JAMES L.
Oak Ridge National Labora-
tory,
Oak Ridge, Tenn.

ERICSON, RUDOLPH C.
Northern Indiana Public
Service Co.,
5265, Hohman Ave.,
Hammond, Ind.

EVANS, CLAIR O.
Phelps Dodge Copper Prod-
ucts Corp.,
40 Wall St.,
New York, N. Y.

EVERETT, RALPH H.
M. J. Merkin Paint Co., Inc.,
1441 Broadway,
New York, N. Y.

EVERHART, E. WAYNE
The Permanente Metals
Corp.,
P. O. Box 1451,
Spokane, Wash.

F

FAIR, W. F., JR.
Mellon Institute,
Fifth Ave.,
Pittsburgh, Pa.

FARKAS, HOWARD
The U. S. Stoneware Co.,
60 East 42nd St.,
New York, N. Y.

FASOLD, G. ARTHUR
The Philip Carey Mfg. Co.,
Wayne Ave., Lockland,
Cincinnati, Ohio.

FENNER, OTTO H.
Monsanto Chemical Co.,
1700 S. Second St.,
St. Louis, Mo.

FERGUSON, W. C.
J. M. Tull Metal & Supply
Co., Inc.,
285 Marietta St. N. W.,
Atlanta, Ga.

FERNANDEZ, HENRY J.
Republic Oil Refining Co.,
P. O. Box 1191,
Texas City, Tex.

FINNELL, THOMAS C.
Westinghouse Electric Corp.,
P. O. Box 2205,
Buffalo, N. Y.

FLEMING, THOMAS J.
Associated Telephone Co.,
Ltd.,
1314 Seventh St.,
Santa Monica, Calif.

FLENTJE, MARTIN E.
American Water Works Co.,
50 Broad St.,
New York, N. Y.

FLINT, J. W.
Cities Service Gas Co.,
P. O. Box 1162,
Wichita, Kan.

FLOR, LOY I.
La Mesa Lemon Grove &
Spring Valley Irrigation Dis-
trict,
4769 Spring St.,
La Mesa, Calif.

FLYNN, E. D.
Oliver United Filters, Inc.,
2900 Glascock St.,
Oakland, Calif.

FOLEY, FRANCIS B.
The Midvale Co.,
Nicetown,
Philadelphia, Pa.

FOLSE, J. B.
Great Southern Supply Co.,
Inc.,
2120 S. Wayside Dr.,
Houston, Tex.

FORREST, MATHEW G.
Gibbs & Cox, Inc.,
21 West St.,
New York, N. Y.

FRANCIS, HOWARD T.
Armour Research Founda-
tion,
35 W. 33rd St.,
Chicago, Ill.

FRIANT, STEWART
Dearborn Chemical Co.,
2205 South Road,
Baltimore, Md.

FURGASON, C. A.
Ladish Co.,
5481 S. Packard St.,
Cudahy, Wis.

G

GAIDO, S. J.
Pipe Line Service Corp.,
P. O. Box 373,
Harvey, La.

GARDNER, G. DOUGLAS
U. S. Bureau of Mines,
Coal to Oil Demo. Div.,
Louisiana, Mo.

GEHLEN, CARL
E. I. du Pont de Nemours
& Co., Inc.,
350 Fifth Ave.,
New York, N. Y.

GLEASON, ALVIN T.
United Gas Pipe Line Co.,
P. O. Box 1407,
Shreveport, La.

GLENN, DENIS
United Gas Pipe Line Co.,
P. O. Box 780,
Wichita Falls. Tex.

GOODRICH, CLINTON R.
Public Housing Administra-
tion,
Texas & Pacific Passenger
Bldg.,
Fort Worth, Tex.

GRAHAM, ROBERT A.
Central Electric & Gas Co.,
144 South 12th St.,
Lincoln, Nebr.

GRAY, R. M.
Long Beach Oil Develop-
ment Co.,
255 S. Santa Clara Ave.,
Long Beach, Calif.

GREBSTAD, ERNEST H.
Southern California Gas Co.,
1700 S. Santa Fe,
Los Angeles, Calif.

GREEN, M. C.
Green Contracting & Engr.
Co., Inc.,
Union National Bank Bldg.,
Wichita, Kan.

GRIBBLE, CHARLES G., JR.
Metal Goods Corp.,
711 Milby St.,
Houston, Tex.

GRIFFITH, DEAN O.
Shell Pipe Line Corp.,
P. O. Box 318,
Houston, Tex.

GUTHRIE, JOHN M.
Union Switch & Signal Co.,
1789-1807 Braddock Ave.,
Swissvale, Pa.

H

HAAS, D. MARSHALL
Humble Oil & Refining Co.,
P. O. Box 3455,
Baytown, Tex.

HALBIG, JOHN J.
The American Rolling Mill
Co.,
Middletown, Ohio.

HALL, JESS E., JR.
Weatherford Spring Co.,
202 West Bridge St.,
Weatherford, Tex.

HALL, W. QUENTIN
Ethyl Corp.,
Baton Rouge, La.

HAMSTEAD, A. C.
Carbide & Carbon Chemical
Corp.,
South Charleston, W. Va.

HARING, WALTER J.
Quaker Chemical Products
Co.,
Conshohocken, Pa.

HARTMAN, H. F.
Humble Oil & Refining Co.,
P. O. Box 3292,
Baytown, Tex.

HARVEY, CLARENCE C.
Ethyl Corp.,
P. O. Box 341,
Baton Rouge, La.

HECHT, MAX
Consulting Engineer,
5835 Alderson St.,
Pittsburgh, Pa.

HEGER, J. J.
Carnegie-Illinois Steel Corp.,
Frick Bldg.,
Pittsburgh, Pa.

HELMRATH, NORMAN K.
Victor Chemical Works,
11th & Arnold Sts.,
Chicago Heights, Ill.

HENDERSON, MERVIN W.
Ajax Pipe Line Corp.,
P. O. Box 1246 S.S.S.,
Springfield, Mo.

HENNEK, E. P.
Central Electric & Gas Co.,
144 S. 12th St.,
Lincoln, Nebr.

HERZLER, RALPH E., JR.
Reynolds Metals Co.,
Wrigley Bldg.,
Chicago, Ill.

HIGDON, VICTOR E.
Liquid Plastics Co. of Calif.
640 Broad Ave.,
Wilmington, Calif.

HIGGINS, J. D., JR.
J. D. Higgins Co.,
Neil P. Anderson Bldg.,
Fort Worth, Tex.

HOIBERG, ARNOLD J.
Lion Oil Co.,
El Dorado, Ark.

HOLCOMB, WILLIAM D.
Bridgeport Brass Co.,
3453 West 47th Pl.,
Chicago, Ill.

HOLMES, LAIRD E.
The Ohio Oil Co.,
Robinson, Ill.

HOLTMAN, CLEMENS W.
American Radiator & Stan.
San. Corp.,
1541 S. Seventh St.,
Louisville, Ky.

HOOKANSON, KENNETH G.
H. M. Harper Co.,
2620 Fletcher St.,
Chicago, Ill.

HOPKINS, JOHN R.
The Tapecoat Co.,
1564 Valentia St.,
Denver, Colo.

HOPPER, EDWARD W.
Crucible Steel Co. of
America,
Oliver Bldg.,
Pittsburgh, Pa.

HORVATH, Louis
The Ohio Bell Telephone Co.,.
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Corrosion Abstracts

ATMOSPHERIC CORROSION

Corrosion Resisting Materials. Paper Before AAR, Elec. Sec., Ann. Mtg., Chicago, Sept 30-Oct. 2, 1947, *Railway Age,* 123 No. 17, 45 (1947) Oct. 25.

Discussion of corrosion resistant materials which were subjected to salt air. They include various types of aluminum alloys, brasses, Muntz metal, bronzes, copper, copper-nickel and chromium-nickel alloys, malleable ingot and wrought iron, copper bearing iron and steel, carbon, chromium and chromium-nickel steels. Generally, bronzes offered the highest resistance to corrosion and good results were also obtained with chromium-nickel-molybdenum and chromium-nickel steels, and silicon iron.—INCO.

Tarnishing and Related Phenomena. U. R. Evans, *Sheet Metal Ind.* (Eng.), 24 No. 247, 2189 (1947) Nov.

Growth of oxide or sulfide films on metals may obey various laws. Where cracks, pores or other cavaties appear, parabolic, rectilinear or logarithmic equations may govern growth, but in the absence of such complications the relation between thickness and time T is most simply expressed as $dy/dt = k_1/y$, where the constant K_1 is related to the electrical properties of the film-substance by Wagner's equations. These show that films of high electric resistance (e.g. beryllia or alumina) should confer good resistance to film-growth, i.e., they protect the metal; electronic and ionic conductivity are both needed if the film is to thicken quickly. Sulfides contain more lattice defects than oxides, and the presence of sulfur in a film reduces its protective properties; metals which undergo no visible change when exposed to pure air at ordinary temperatures may tarnish readily if sulfur compounds are present. At high temperatures the oxidation-rate, although appreciable in the absence of sulfur, is increased if the atmosphere contains sulfur compounds. The resistance of a copper-aluminum alloy to oxidation at high temperatures, or of a silver-copper-aluminum alloy to tarnishing in polluted air at ordinary temperatures, is greatly improved if the alloy has received a preliminary treatment designed to develop an invisible film of pure alumina (free from copper and/or silver) on the surface. The significance of these matters to electroplaters is discussed.—ALL.

Lengthening the Service Life of Induced Draft Fans. A. F. Tagin, *Eng. D.* (Am. Ed.) 4, 443 (1947) Sept. Translated and abstracted from *Promishlennaya Energetika* (USSR), 4, No. 2, 12-13 (1947).

Method described consists in coating fan blades and internal casing surfaces with a layer of water-glass. Excellent service results are claimed.—BLR.

BACTERIAL CORROSION

Effect of Sulfur Bacteria on Corrosion. L. Liberthson, L. Sonneborn Sons, Inc., Paper before AISE, Ann. Conv., Cleveland, Oct. 4, 1946, *Iron & Steel Engr.,* 24, No. 6, 69-72; Disc. 72-73 (1947) June.

The phenomenon of bacterial deterioration of cutting oil emulsions is used as an illustrative link to indicate why and how sulfur reducing bacteria may well be regarded as a subject for study by the industrial microbiologist. Literature is briefly surveyed to emphasize the intersection between the lines of investigation familiar to the iron and steel technologist and the lines normally regarded as primarily biological and to underline the research trends and possibilities in the field of corrosion of iron and steel in the area where it overlaps existing knowledge of chemo-autotrophic microorganisms. 20 refs.—INCO.

BEARING CORROSION

Present Day Bearings. E. Crankshaw, Cleveland Graphite Bronze Co., Paper before SAE Pittsburgh Sect., Nov. 26, 1946, *SAE J*, **55**, No. 8, 70-71 (1947) Aug.

Care in assembling and operating vehicle engines is the touchstone to long and satisfactory performance of precision bearings. Proper installation in regard to crush is discussed and illustrated. Greatest number of bearing failures stems from foreign material in the oil from which excessive shaft wear, fatigue or seizure are certain to follow. An example of how corrosion etches away the lead of copper-lead bearings leaving a dendridic copper structure which quickly fails from fatigue is shown. Analysis of bearing loads, speeds, temperature also included.— INCO.

CATHODIC PROTECTION

Cathodic Corrosion Protection. *Steel*, **121**, No. 19, 106-07, 124 (1947) Nov. 10.

Essentially, cathodic protection means that the structure to be protected serves as the cathode of a battery. This battery is set up by placing metal anodes in the soil near the buried structure and connecting these with a wire; the earth acts as an electrolyte. Magnesium anodes, made of metal or alloy higher in the electromotive series than the metal to be protected, were considered valuable because of their high driving voltage. By reversing the current flow the metal prevents weakening of structure by corrosion. In the so-called packaged anode described, the anode and the lead wire are placed in a cloth bag containing the chemical required for the mud, the bag is placed in the ground, and the wire connected to the cathode, water being poured over the anode to give the chemicals the moisture needed to form the chemical mud. Such magnesium anodes, applicable for protection of pipelines, cable, storage tanks, sheet piling, lead sheath cable, steel poles and tower footings, are expected to produce cheaper installation and greater ease of maintenance.

Magnesium Ribbon Used to Protect Pipeline. Anon, *AGA Month,* **30**, No. 1, 30, (1948) Jan.

A high-pressure gas transmission line of The Manufacturers Light & Heat Co., Pittsburgh, was selected for the first experimental installation in the U. S. in which a magnesium ribbon was placed alongside a gas line to protect the steel pipe from underground corrosion. About 1000 ft. of an 8-in. high pressure line near Florence (Washington Co.), Pa., were chosen. When this section of pipeline was installed in June, no protective measures were taken against galvanic corrosion. The pipeline was located about 2 ft. beneath the surface of the ground, and a small excavation was made laying bare the steel pipe. One end of the magnesium ribbon, ⅜ in. by ¾ in. covering a small steel wire, was welded to the pipe. With a cable laying plow, a narrow trench was cut along the pipeline and the ribbon laid parallel to the steel pipe. Dow Chem. Co. producers of magnesium, claim that a contact of the magnesium with the steel, through the medium of the earth, will prevent for about 10 years the formation of galvanic cell corrosion generally caused by an electrochemical reaction between the pipe and chemicals in the soil surrounding it.—CEC.

Problems in Cathodic Protection. Frank E. Dolson., *J. AWWA,* **39**, 1079-1089 (1947) Nov.

A general discussion of the problems involved in thus protecting underground water-pipe against corrosion.—BLR.

Electrical Instruments and Measurements in Cathodic Protection. J. M. Pearson, *Corrosion,* **3**, 549-566 (1947) Nov.

Points out the uses and limitations of techniques or instruments now in use.—BLR.

Use of Magnesium, Zinc, Aluminium and Their Alloys in the Cathodic Protection of Steel in Salt Water. R. R. Rogers & C. E. Viens, *Can. Metals & Metall. Inds,* **10** No. 9, 18+ (1947) Sept.

The laboratories of the Department of Public Works, Ottawa, were consulted regarding methods of combating the corrosion of steel piling in sea water. Three series of cathodic protection experiments were performed: 1) Experiments with cylindrical cathodes. 2) Experiments with long strip cathodes. 3) Intermittent immersion experiments. The cathodic protection of steel in synthetic sea water was quite successful in the small-scale experiments described. It is felt that pilot-scale tests in actual sea water would be justified. In selecting the anode materials for these larger scale tests, magnesium or high magnesium alloys should be considered first in cases where protection is of the utmost importance and the anode corrosion rate is secondary. In cases where it is important to have a comparatively low anode corrosion rate even though the protection may not be of so high an order, pure zinc or the 20-80

magnesium-zinc alloy would appear to be most desirable. It should be pointed out that aluminum may be more successful as an anode material in other types of solution. Also, there may be aluminum alloys outside the range of compositions investigated in this work which will give good protection in salt water. When back-fills and packaging have been studied more fully, the anodic protection picture may change considerably.—ALL.

Cathodic Protection Rectifiers. W. L. Roush & E. I. Wood, Westinghouse Elec. Co., Paper before NACE, Ann. Mtg., Kansas City, May 7-9, 1946, *Corrosion*, **3**, 169-172 (1947) Apr.

Rectifiers are replacing the engine generator sets and wind chargers where rural electric power is available. Air-cooled and fan-cooled rectifiers are discussed.—INCO.

CHEMICAL CORROSION

Liquid Designed to Prevent Corrosion in Oil Tanks. *Heat., Piping & Air Cond.*, **20**, No. 1, 248 (1948) Jan.

Announcement of "Tank Saver," a liquid designed to prevent corrosion in oil storage tanks, thereby increasing tank life. The material, being heavier than water, goes to bottom, mixes with water in tank (caused by condensation) and forms a protective film. Product is also highly alkaline, and neutralizes any acid that may be in oil.—INCO.

Bronze Wedge, Monel Seat Rings Used in Gate Valve. *Heat., Piping & Air Cond.*, **20**, No. 1, 248 (1948) Jan.

Announcement of new bronze gate valve for 200 psi service, with newly designed seating combination—a high tensile bronze wedge seating against Monel seat rings of a hardness about 2½ times that of valve body bronze. Seat rings are expanded into body and are equivalent to integral faces. Recommended for service where severe conditions exist as in oil refineries, dye houses, food, rubber and chemical plants.—INCO.

How to Avoid Failures of Brass Due to Season Cracking. Anon., *Elect. Mfg.*, **40**, No. 1, 100-03+ (1947) July.

Season cracking is caused by a susceptible chemical composition, stress and corrosion. All three must be present to produce failure but the degree of each is a moot question. Obviously there can be no degree to the chemical composition, but, in the copper-zinc series of alloys the exact composition which is free from season cracking tendencies is debatable.

The generally accepted rule is that 20% zinc is the dividing line. Alloys containing more than 20% zinc will fail under stresses far below the elastic limit in a corrosive atmosphere, while alloys containing 20% zinc are not affected. However, this is a purely empirical rule and though a valuable indicator, should not be accepted as true for any particular design until the process itself has been tested with the selected material. Various hypotheses relative to the role of the stress are reviewed. In any case, internal stresses due to cold working should be eliminated by suitable heat treatment. The necessary corrosion may be caused by corrosive atmospheres so mild as to cause no corrosion except in highly-stressed materials. An improperly annealed rivet wire stored for less than 1 month in an ammonia atmosphere, not discernible by odor, failed by season cracking. Mercury and mercury compounds, ammonia and amines as found in plastics and soldering fluxes, dilute sulfuric acid and even sulfur dioxide in the presence of water vapor are sufficiently corrosive to cause season-cracking failure. In addition to the ammonia and amines found in soldering fluxes, the tin or lead in the solder aggravates the condition. Accelerated tests for tendency to corrosion cracking are given.—CEC.

Corrosion Data: Melamine-Formaldehyde Resin and Dilute Hydrochloric Acid. Anon., *Clad News*, **8**, No. 2, 7.

Table gives results of corrosion tests in mixtures of melamine-formaldehyde resin and dilute hydrochloric acid, on Monel, nickel, Inconel, Ni-Resist (Type I), and mild steel. Above solution is added to pulp in a process for improving the wet strength of paper.—BLR.

Sulfur Dioxide vs. Materials of Chemical Plant Construction. Parts I-III. *Chem. Eng.*, **54**, No. 7, 221-222+ (1947) July; Ibid., No. 8, 209-210+ (1947) Aug.; Ibid., No. 9, 209-210+ (1947) Sept.

Part I has sections on the use of Worthite (high nickel-chromium-molybdenum-steel) by W. E. Pratt; on nickel and nickel alloys by W. Z. Friend; and on silicons by J. A. McHard. Part II has sections on rubber linings by O. S. True; on Durimets T and 20 by W. A. Watkins; and on aluminum and its alloys by E. D. Verink and others. Part III deals with Haveg; lead; tantalum; Hastelloy; stainless steel; chemical stoneware; wood tanks; carbon and graphite; glass-lined steel.—BNF.

COATINGS

Aluminum. A. R. McNeil, *Month. Rev. Am. Electroplaters' Soc.*, **31**, 434-41 (1944); *Brit. Asbsts.* **B-1**, 79 (1947).

Working details for mechanical, chemical and anodic finishes are given, while organic and electroplated finishes are mentioned. Anodic films are suitable bases for organic finishes; zinc chrome primer may be used to replace anodising where this is inconvenient.—RPI.

The Painting of Aluminum. J. J. Meynis de Paulin, *Rev. de l'Aluminum*, **24**, 137-138, 309-317, 325-331 (1947).

Covers surface preparation (degreasing, mechanical roughening of surface, pickling, chemical oxidation, anodic oxidation) and the paints and lacquers used (properties of the various bases, passivating pigments, etc.).—BNF.

Mildewproofing Protective Coatings. A. Minich & M. Goll, *Paint, Oil & Chem. Rev.* **109**, No. 24, 6-7+ (1946).

Discussion of the development of fungicides for inclusion in protective coatings of all types, both for interior and exterior use. Chlorinated phenols prove effective in coatings with a casein or protein base; phenyl mercurials, and especially phenyl mercury naphthenate, are effective in other types of coatings. A report on a study of the toxicity of coatings containing this compound is given in detail, and the conclusion drawn is that, when used in amounts effectively controlling mildew growth (0.2% mercury on the weight of paint) it causes no serious health hazard.

New Industrial Coatings Resist Abrasion and Corrosion. J. C. Montgomery, *Can. Pain & Varn. Mag.*, **21**, No. 10, 7-8+ (1947) Oct.

Various corrosion and abrasion-proof materials are now being used to line pipes, valves, fitting and machinery for handling chemicals and other solutions. Waterous Ltd., Brantford, Ont., supply four types of coating materials: a specially compounded synthetic rubber, a resin composition, a thermoplastic resinous mixture, and a phenolic-type resin. Coatings produce a smooth, slippery surface which facilitates the flow of materials and eliminates accumulation of matter which may cause corrosion. As all surfaces receiving the coatings must be chemically clean, all parts, including the inside of pipes and fittings, are sand-blasted. The synthetic rubber compound, which may be applied to the common metals and on the most complicated surfaces, is the most useful coating. It has a bond of 1100 psi to steel, 650 psi to aluminum, brass and copper, and 850 psi to concrete. It may be applied in liquid form by brushing, flowing, or dipping, or may be cemented on in sheet form. It can withstand the corrosive action of many acids and solutions to a temperature of 250° F. (121° C.). Equipment thus coated may be shipped without damage in temperatures down to —58° F. (—50.4° C.). A 1/16-in. coating is sufficient for normal temperatures, but coatings ⅛-in. thick are recommended for resistance to abrasion and higher temperatures. Details are given of the methods used in lining and coating pipes and fittings. The three other coating materials may be applied with spray guns. The resinous composition can be brushed on or sprayed with a pressure cup gun. Guns with suction cups are used for the other two materials. The resinous composition withstands many oxidizing solutions from which natural or synthetic rubber would not afford protection. It has an optimum operating temperature of 170° F. (77° C.) and a heavy duty coating is 0.032-in. thick. The thermoplastic resinous mixture is used mostly to protect tanks, machinery and framework against the corrosive action of moisture-laden acid and alkali fumes. It also affords protection against many corrosive liquids, but is not satisfactory at temperatures above 130° F. (54° C.). It is not recommended where abrasion resistance is a major requirement. The phenolic-type resin finish tends to be brittle and lacks the rugged properties of the other coatings.—ALL.

Porosity of the Surface Protective Layers on Steel Plate Food Cans. E. Nehring, *Korros. u. Metallschutz*, **20** No. 1, 37-42 (1944) ; *Chim. et Ind.*, **52**, Nos. 1-6, 81 (1944).

Electrolytically tinned coatings are more porous than normal tinplate, but those produced by the Bezitit process are good. Black plates varnished before fabrication of the cans are poorly protected owing to the damage caused during fabrication. Varnish films sprayed on to phosphated cans are less porous and the effect of pores is generally localized.—RP.

A Pipe Within a Pipe. Anon. *Ind. & Eng. Chem.* **39**, No. 9 16A, 22A (1947) Sept.

Quite a few years ago a Western sewer

construction company decided that what this country needed was a better sewer pipe. The concrete pipe used at that time disintegrated under the action of hydrogen sulfide released from the sewage. This disintegration often attained the rate of 2 in. a year. A coating has been developed. This coating is a polyvinyl chloride thermoplastic extruded as a tube slightly smaller than the pipe to be protected and having a wall 0.06-in. thick. The liner is coated with a solution of vinyl resin-type adhesive which is allowed to dry before the tube is inserted in the pipe. Once assembled, an induction coil heats the pipe and resoftens the adhesive, and air pressure expands the liner to effect a uniform bond. The liner is actually enlarged by this process. Thus there are no strains in the final product. To insure that the contents of the pipe do not come in contact with metal at any point, flange faces are covered with a specially formulated vinyl resin composition having the properties of a synthetic rubber gasket. At the same time the liner is molded around the turn of the flange and blended with the gasket material under heat and pressure to form a continuous corrosion-resistant surface throughout the joint. This procedure necessitates plant processing, as it is not feasible to cut and flange this type of pipe in the field. The lining material is stable to water at 200° F. Tests lasting 90 days at room temperature indicate that it is not affected by any of a number of industrial liquids, including concentrated and dilute acids, organic acids and solvents, petroleum and vegetable oils, soaps and alkali solutions. Strong caustic solutions tend to embrittle the material slightly, but for special installations where continued resistance to such solutions is required, formulations containing different plasticizers can be made which will be caustic stable. (Testing methods given). Initial production of the pipe will be in sizes between 2 and 4 in. However, eventually all sizes of common welded-steel pipe will be available with this lining. There are as yet insufficient data to determine the exact projected selling price of the material. However, the American Pipe & Construction Co., Los Angeles, Calif., the producers, say it will compare with rubber pipe now selling at around $1.50 a foot in the 2-in. diameter size. In the same size, Saran is priced at $3.50 a foot and Pyrex is about $1.40. Essentially the same resistance to chemical attack offered with the plastic-lined pipe may be given almost any metal or concrete surface by direct application of a fluid preparation that may be applied with a brush or spray gun.—CEC.

Paint Destruction and Metal Corrosion: Zoological Aspects. T. C. Nelson & E. R. Kodet, *Off. Pub. Bd., Rep. PB.* 22475, 16pp. (1944); *NPVL Abst.* No. 118, 184 (1946).

Visual observations have been made of coated glass and steel panels and uncoated steel panels immersed in sea water for various lengths of time at several locations along the east coast of the USA. Further evidence of anaerobic corrosion was obtained and the type of paint destruction by barnacles and oysters was observed. Oysters appear to affect only the surface of the paint, but barnacles gouged out the paint, sometimes completely penetrating the film. Photographs are attached.

Regalvanizing of Welded Joints. George H. Ohmer, *Corrosion,* **3,** 580-584 (1947) Nov.

Describes and illustrates procedure for application of a low-melting zinc-base alloy to areas on galvanized objects where the original zinc coating has been destroyed either by welding or by other means.—BLR.

Protective Undercoaters. B. Rawson, *Com. Car J.,* **68,** No. 9, 1300-7 (1947); *Austin Tech. News,* No. 188, 6 (1947).

Undercoaters are supplied in the form of a thick compound, which is sprayed on to a depth of approximately ⅛-in. and dries firm, but never sets hard. They seal out rust, deaden noise and withstand abrasion, and are impervious to salt, moisture and acids; they also may be used to bring up crankcase temperatures.

Paint Progress Through Weathering Tests. Anon. *Paint Prog.,* **6,** No. 2, 6 (1946).

A brief account of how a new type of zinc oxide would be tested, including examination of the zinc oxide in the laboratory, incorporation in many different types of paint, accelerated and natural weathering tests and finally trial painting of houses in different parts of the country.—RP.

Protection of Interior of Steam Condenser. Munitions Supply Labs., *Paint Notes,* **2,** No. 2, 52-4 (1947).

Results are given of tests on various painting systems used for protecting the interior of steam condensers. Best results were given by a system consisting of one coat of alkyd-based red lead primer and two coats of aluminum-pigmented spar varnish.

CONDENSATE WELL CORROSION

A 3-Year-Old Corrosion Research Project Will Be Extended Over a 5-Year Period, According to a Research Committee of NGAA. *Natl. Petro. News,* **39,** No. 25, 45 (1947) June 18.

The project is cooperative, including contributions amounting to $60,000 from 25 producing companies. Specific reports have been obtained on 52 different inhibitors and alkalis. Problems for further study include the following: 1) determination of the chemical composition of natural inhibitors believed present in non-corrosive wells, 2) the action of known inhibitors, 3) the most effective means of neutralizing corrosive wells, 4) protective coatings for tubing, using different types of alloys, and 5) costs of corrosion inhibition by chemical injection compared with the use of alloy fittings and pipe.

Corrosion of Oil-Well Equipment. L. C. Case, Gulf Oil Corp., Paper before ASME, Natl. Conf. on Petro. Mech. Eng., Houston, Oct. 5-8, 1947, Abstr. *Oil & Gas J.,* **46,** No. 24, 147-148 (1947) Oct. 18.

Corrosion is, in general, due to water. It is shown that water-oil ratio is significant, depending upon the nature of the oil and water. Chemical attack on oil-well equipment is often accompanied by the corrosion-wear process and by galvanic current corrosion. Resistant materials, coatings, and chemical neutralization are not too successful from an economical and practical standpoint. Formaldehyde is rather effective in certain sulfide areas and oil-wetting agents give promise of further development.

Sub-surface Sucker-Rod Pumps — Factors in Their Selection and Use. R. L. Chenault, Oil Well Supply Co., Paper before ASME Natl. Conf. on Petro. Mech. Eng., Houston, Oct. 5-8, 1947, *Oil & Gas J.,* **46,** No. 24, 104+ (1947) Oct. 18.

Typical pump assemblies are described and shown. Corrosion problem is briefly referred to. Choice of suitable materials, reduction of maximum temperatures and slow pump speed are chief means of combatting corrosion from hot gases. Parts most affected by these are named. Materials are not discussed.—INCO.

Corrosion in Condensate Gas Wells. N. Hackerman & D. A. Shock, Univ. of Texas, *World Oil,* **127,** No. 7, 198-200+ (1947) Nov.

Studies of condensate well corrosion in-

dicate that the presence of fatty acids, carbon dioxide, condensed water and dissolved salts usually causes corrosion and that the rate and type of corrosion depend on the nature of the corrosion product. The scale formed in most wells is relatively porous and sometimes nonadherent, permitting further corrosion, while an impermeable, adherent film is formed in the few non-corrosive wells by "natural inhibitors," probably polar organic materials present in the liquid hydrocarbon phase. Reviews tests made in three wells. Severe corrosion may be controlled by the used of alloys, neutralizers and inhibitors. 16 refs.

Inhibiting Subsurface Sulfide Corrosion. P. L. Menaul, Stanolind Oil & Gas. Co., *World Oil,* **127,** No. 6, 150-152+ (1947) Oct.

Corrosion of subsurface equipment by sulfide brines can be almost entirely prevented by the daily injection of formaldehyde into the annulus of the well in the proportions of 1 quart of formaldehyde per 50 bbls. of produced water. In initiating this treatment, the well is first surveyed by the corrosion chemist; the well is insulated from flow line currents; scale is removed from well equipment; the produced water is analyzed; the amount of formaldehyde to use daily is determined; and the type of injection chosen. For greater saving, it is recommended that all wells drilled into sour or sulfide production be treated with formaldehyde as soon as they are put into production. The effluent water from treated wells should be periodically checked to ascertain that the formaldehyde is circulating. The continued use of old equipment beyond the previous life estimated is one of the benefits attributed to the use of formaldehyde. A summary by fields of the cost data on formaldehyde injection is included which indicates a net saving per well-year of $632 for a total of 94 wells in the Kansas-Texas area.

Test of Nickel-Plated Pipe in Corrosive Distillate Well. B. B. Morton. *Corrosion,* **3,** 592 (1947) Nov.

Illustration shows value of above as determined by 6-month exposure under field conditions.—BLR.

Corrosion Studies in Natural Gas Condensate Wells; Protective Layers. D. A. Shock & Norman Hackerman, Univ. of Texas, *Ind. & Eng. Chem.,* **39,** 1283-1286 (1947) Oct.

Absence of localized attack and the low rate of general attack in a certain type of natural-gas condensate well is believed to be caused by the presence of a naturally occurring inhibitor in the hydrocarbon phase which reacts with the steel surface to form a thin but highly protective layer. An investigation of the hydrocarbon phase disclosed the presence of a constituent not found in a corrosive well. Choice of an inhibitor for a corrosive well is discussed. Naphthenic acid was found to be satisfactory. The protection provided by sodium dichromate under these conditions is also discussed. 16 refs.—BLR.

CONSTRUCTION MATERIAL

Production of Iron-Free Aluminum. E. A. Gee, W. K. Cunningham & R. A. Heindl, *Ind. & Eng. Chem.*, **39**, No. 9, 1178-1188 (1947) Sept.

On page 1185 there is a brief, useful section on materials of construction used in the plant.

Cast Alloys Stabilized with Columbium or Titanium Alloys. E. A. Schoefer, *Alloy Casting Bull.*, No. 10, 1-7 (1947) May.

Detailed data from Corrosion Progress Report No. 18 on the influence on corrosion resistance of columbium and titanium additions to CF alloys by H. A. Pray, F. W. Fink and H. F. Haase, to the Alloy Casting Inst. are summarized. Titanium is unsatisfactory because, although intergranular corrosion is prevented, the alloy has an excessive corrosion rate in boiling HNO_3 after exposure to 1200° F. Columbium in the amount of 8 times the carbon content is sufficient to protect the alloys from intergranular attack and in range of 8-10% does not impair the over-all corrosion resistance after alloy has been exposed to 1200° F. A stabilizing treatment at 1600° F. is effective in improving the columbium-containing alloys, particularly those low in chromium and can be used in place of the usual 2075° F. quench anneal. Addition of columbium to a molybdenum containing CF alloy results in poor corrosion resistance after exposure to 1200° F., and a special alloy outside of the normal CF chemical ranges is required for satisfactory corrosion resistance. Castings of the CF-10 type can be protected against intergranular attack through addition of columbium to a properly balanced alloy. Schematic diagrams show effect of columbium and titanium on corrosion in boiling 65% HNO_3 and

of a 1600° F. stabilizing treatment on corrosion of CF-10 carbon type cast alloys. HNO_3 corrosion rates of molybdenum-columbium alloys (19-9) are tabulated, and drawings of structures illustrated.—INCO.

Design of Pressure Vessels for High Temperature, High Pressure Reactor Service. E. W. Jacobson & B. M. Wedner, Gulf Res. & Devel. Co., & T. G. Beckwith, Univ. of Pittsburgh, Paper before ASME Natl. Conf. on Petro. Mech. Eng., Tulsa, Oct. 7-9, 1946, *Proc. of ASME Petro. Mech. Eng. Conf. 1946* (publ. June, 1947), 153-162.

For higher ranges of pressure and temperature than covered by the ASME Boiler Code, special attention must be paid to problems of closures, supports, creep and differential expansion. Design problems in the hydrogenation process are typical. Use of 18-8, Types 321 and 347, is mentioned. For gaskets, silver-plated SAE 1020, copper Armco iron and nickel are commonly employed. Types of closures are described and drawn with materials. In discussion, the tendency of 18-8 steels to work harden rapidly and of Type 347 pipe to crack during welding is mentioned. A special procedure developed by the M. W. Kellogg Co. is used in making up flanged joints with 18-8 bolting, due to the low yield point of this alloy. The joint is first made up using a low alloy steel bolting material, such as SAE 4140, employing a controlled tightening procedure and a torque wrench to pull up bolts to a predetermined and uniform torque in order to set the gasket. The 4140 bolts are then replaced one by one with the 18-8 service bolts. 21 refs.—INCO.

Stainless Steel Piping Selection of Pipe Joints. J. D. Mattimore, *Heat., Piping & Air Cond.*, **19**, 84-87 (1947) Nov.

Discusses considerations involved in selecting types of joints for maintaining sanitary conditions, avoiding fluid contamination, and reducing the possibilities of crevice-type corrosion.—BLR.

Effect of Notching on Materials of Construction Under Static and Dynamic Tension. (Maximum Testing Velocity 29 Feet Per Second.) Georges Welter, *Metallurgia*, **36**, 283-286 (1947) Sept.

Gives results of static and dynamic tests performed in order to determine the effect of notches in specimens of various construction materials. Total energy, elongation, and energy absorbed per unit volume, for 6 different materials, were

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measured on specimens tested at a rate of straining of 0.005 ft. per sec. and compared with the same values measured on identical specimens strained about 20,-000 times faster. Tests confirm previous conclusions to the effect that the dynamic strength of cylindrical 2-in. gauge length specimens, at a speed of 11.78 ft. per sec., is up to 60% higher than the static strength, depending on the material tested; in the case of zinc, it is 100% higher. (To be continued.)—BLR.

Metallurgical Properties of High Yield Strength Seamless Line Pipe. A. B. Wilder & J. D. Tyson, *Weld. J.*, **26**, 872-880 (1947) Oct.

Results of a study of a new grade of seamless pipe with a 52,000 psi minimum yield strength and 75,000 psi minimum tensile strength. The steel of this pipe contains 0.40% maximum carbon and 1.40% maximum magnesium as compared with 0.30% and 1.25%, respectively, in the steel commonly used for line pipe. Various factors relating to bend tests, various welding-rod combinations, and the influence of chemical composition of the steel on the weld properties, were investigated.—BLR.

Application of Corrosion Resisting Materials to Railroad Electrical Construction. *Mech. Eng.*, **121**, 620-621 (1947) Nov.

Summarizes data from tests made over a period of years on corrosion-resisting materials. In all cases, samples of various metals and alloys were suspended overhead and were removed, cleaned, examined and weighed at intervals. The materials included various types of aluminum alloys, brass, leaded brass, Muntz metal, a wide variety of bronzes, copper, copper-nickel alloy, chromium-nickel alloy, malleable iron, ingot iron, wrought iron, carbon steel (black), carbon steel (galvanized), copper-bearing iron and steel, and chromium-nickel steel.—BLR.

Clad Steels. *Matl. & Meth.*, **26**, 97 (1947) Sept.

Materials & Methods manual presents the basic facts about clad steels. Covers properties of materials used; forming machining, shearing and punching, flame cutting, welding, heat treating, cleaning, finishing and applications.—BLR.

Cutting Corrosion Corrosion-Resistant Alloys by the "Flux-Injection" Method. *Machy.*, **54**, 165-166 (1947) Oct.

Describes fabrication of stainless steels by a combination of flame-cutting and welding by above method in which a special dry non-metallic flux is carried directly by the oxygen stream to cope with the refractory oxides formed by the alloy elements.—BLR.

Passivity in Chromium-Iron Alloys; Adsorbed Iron Films on Chromium. H. H. Uhlig, Mass. Inst. Technol., *Metals Technol.*, **14**, TP. 2243, 10 pp. (1947) Sept.

Discusses a mechanism based not on physical protection by an oxide or similar compound, but on a change in the tendency of surface metal atoms to react chemically. It was shown by electroplating or evaporating iron on a chromium surface and immersing in nitric acid that iron in contact with chromium is passive at the interface. Results support the electron-configuration theory of passivity and account for the properties of iron alloys containing over 12-15% chromium (stainless steels). The amount of residual iron increases with time elapsed after deposition and reaction with nitric acid. Study of this effect shows that surface migration is responsible. This suggests a mechanism for the relatively good protection of some very thin metal coatings, especially commercial electrodeposits of chromium on nickel. 14 refs. —BLR.

Concept of the Hydrogen Potential in Steam-Metal Reactions. Carl A. Zapffe, Paper before ASM Cleveland Mtg., 1947, *ASM Preprint* No. 15, 38 pp.

Thermodynamic study of numerous reactions of metals and alloys with moisture resulted in development of the concept of the "hydrogen potential." These potentials provide a basis for calculating the liability of the various metal systems to hydrogen pickup, from the moisture reaction. Calculations for iron, steel, stainless steel, nickel, chromium, manganese, silicon, aluminum, and magnesium are shown graphically. Conditions over a wide range of temperature, and a wide range of humidity and steam pressure, yield calculations which readily explain numerous metallurgical phenomena. 28 refs.—BLR.

Fabrication Notes on Corrosion-Resistant Alloys. J. C. Hohnberg, Alloy Welding & Mfg. Co., Paper, ASME, Tulsa (3/2-5/47); Abstr. *Petro. Processing*, **2** 314-15 (1947) April.

Notes on pressure vessel fabrication from six austenitic and three ferritic grades of stainless steels are presented.

FUNDAMENTALS

Passivation of Stainless Steels. (In French.) L. Guitton, *Metaux et Corrosion,* **22,** 47-60 (1947) Apr.

The first two chapters of a four-chapter article covering the activity and passivity of stainless steel. A general study is made of passivation conditions with respect to stainless steel. Results of application of findings to cold- and hot-worked specimens are discussed.—BLR.

Fundamentals of Corrosion Control. Anon, *Elect. World,* **128,** No. 7, 86-7 (1947) Aug. 16.

Factors which stimulate corrosion are listed, including the following: damp atmosphere, oxygen dissolved in water film, acids, salts, contact of dissimilar metals, presence of depolarizing surface, nonuniformity of the metal. Corrosion due to electrolysis and the use of alloying metals to make the basic metals slightly cathodic, are discussed very briefly. Diagrams illustrating the principle of the electromotive series are included.

Effect of Cold Work on the Rate of Oxidation of Iron. J. Benard & O. Coquelle, *Rev. Met.,* **44,** Nos. 3/4, 82-86 (1947) Mar.-Apr.

Tests in dry air at 850° C. on abraded, rolled and stretched specimens. Oxidation rate did not increase regularly with the intensity of cold work nor was it affected by annealing; authors attempt to correlate changes in oxidation rates with formation of textures.—BNF.

Thin Oxide Films on Aluminum. Earl A. Gulbransen & W. S. Wysong, *J. Phys. & Colloid Chem.,* **51,** 1087-1103 (1947) Sept.

Presents results of a vacuum-microbalance study of the oxidation behavior of aluminum from 200° to 550° C. Results are correlated with observations on the physical and chemical structure of the oxide film. Includes a few electron-microscope observations. 24 refs.—BLR.

Chemical Manifestations of Internal Stress. F. H. Keating, *Sym. on Internal Stresses (Inst. of Metals),* 311-331 (1947) Oct.

Discussion of combined effect of internal stress and corrosive environment. Survey of literature on a stress-corrocracking of the commoner industrial alloys, also recording examples from industrial plant; factors involved in stress-corrosion cracking and tentative explanation of its mechanism. 98 refs.—BNF.

GENERAL CORROSION

The Corrosion of Metals. Part VIII. Aluminum and Its Alloys. *Sheet Metal Ind.,* **24,** 1633-1636 (1947) Aug.

The good corrosion resistance of aluminum is surprising in view of its position in the electromotive series where it has a normal electrode potential of 1.33 volts, being more anodic that most of the common metals, such as copper, iron or lead. Aluminum has a high affinity for oxygen, and the natural oxide film formed on it is highly protective, both against further oxidation by the atmosphere and against attack by many of other media. The protective properties of the oxide film on aluminum are exploited in the anodic oxidation processes.—BLR.

The Corrosion of Metals. Part VIII. Aluminum and Its Alloys. *Sheet Metal Ind.,* **24,** 2026-2028 (1947) Oct.

A review covering solution-potential studies; stress corrosion; influence of forming on stress-corrosion; and effect of composition on stress corrosion cracking. (To be continued.)—BLR.

Discussion, Institute of Metals Division. *Metals Technol.,* **14,** TP 2222, 33 pp. (1947) Aug.

Covers 16 papers which appeared in Feb.-June issues, inclusive. Topics discussed included: metallic solid solutions; structure of copper-zinc alloys; improving cold drawability of 1.5%-manganese magnesium alloy; copper refining—Germany; vacuum metallurgy of lithium; metal-powder compacts; Bismuth-Indium system; oxide films on molybdenum, tungsten, nickel, and their alloys; properties of wrought copper-rich copper-manganese-zinc alloys; effect of prior tensile strain on fracture; solubility of carbon in copper-manganese and copper-nickel alloys; and plastic flow of aluminum sheet under biaxial stresses.—BLR.

Corrosion—Pitting and Dezincification. M. G. Fontana, *Ind. & Eng. Chem.,* **39,** No. 5, 87-A (1947) May.

Various types and examples of dezincification, as well as pitting, are shown and discussed concisely. "Decobaltification" of Stellite No. 1 hard-facing alloy in sulfuric acid slurry containing solid ferrous sulfate is mentioned. The use of nickel-copper alloy instead of brass is recommended where dezincification possibilities are most severe.—INCO.

INHIBITORS

Corrosion Inhibitor. *Prod. Eng.*, **18**, No. 7, 184-186 (1947) July; *Iron Age*, **159**, No. 25, 80 (1947) June 19.

The synthetic chemical CS-CP-501 is compounded to prevent corrosion by vaporizing the moisture in the atmosphere surrounding ferrous metals. The vapor formed is odorless, non-toxic and does not injure the skin. When sprayed on metal, the chemical reacts with the moisture in the atmosphere and forms a protective film. Corrosion can also be prevented by wrapping metal in paper or cloth that has been sprayed with the inhibitor. Mfg. by Chas. Stevens & Co.— INCO.

Compound Inhibits Corrosion Due to Dissolved Carbon Dioxide. *Heat., Piping & Air Cond.*, **19**, No. 4, 164 (1947) Apr.

Morpholine, a volatile compound for inhibiting corrosion due to CO_2 in steam and condensate return lines of heating or processing systems, was developed by Carbide and Carbon Chemicals Corp. It is an alkali which is designed to control acidity due to free CO_2 in the feedwater or CO_2 resulting from decomposition of soluble carbonates. It evaporates with water in definite proportions so that any desired alkaline value in the steam generated can be maintained by adjusting the concentration in the boiler. It is recommended for feedwater treatment where extensive piping or condensing surfaces are present in low or medium pressure systems.—INCO.

Chemical Research at Teddington. *Chem. Trade J. & Chem. Eng.*, **121**, 115 (1947) Aug. 1; *Corros. & Matl. Prot.*, **4**, No. 6, 26 (1947) Nov.-Dec.

Includes outline of investigation of sodium benzoate as a corrosion inhibitor. —INCO.

New Corrosion Inhibitor. *Soap & San. Chem.*, **23**, No. 10, 89 (1947) Oct.

A new corrosion inhibitor, "Steelyfe 11" for steel and ferrous metals, whose active ingredients is salt of an alicyclic sulfonic acid is announced. It gives special protection against corrosive sulfate ions, is in the form of a thin, dark liquid with a flash point of 105° F.; and can be applied by dipping, brushing or spraying. It leaves a transparent coat readily removed by wiping or with degreasers even after several years.—INCO.

INSPECTION

Supersonic Wave Penetration into Materials. Benson Carlin, *Prod. Eng.*, **18**, 169 (1947) Oct.

Table of experimental values of approximate maximum depth of penetration in specific samples.—BLR.

X-Ray Inspection Promotes Casting Quality Control. E. H. Grimm, *Foundry*, **75**, 94-96+ (1947) Oct.

Describes and illustrates use of the above by Auto Specialties Mfg. Co., St. Joseph, Mich., which specializes in products for the auto industry, chiefly cast-steel crankshafts and malleable-iron castings; also hydraulic and mechanical jacks. —BLR.

Gamma Ray Detection of Internal Corrosion. L. R. Keller, Union Oil Co., *Petro. Eng.*, **18**, No. 13, 211-214 (1947) Sept.

Detection of internal corrosion is facilitated by the use of the gamma ray instrument. Commercially known as "Penetron," it operates by measuring secondary radiation from gamma rays that are directed into the metal being tested. An accuracy of plus or minus 5% over its range of measurement, between 0 and 0.75-in. thickness, is obtainable. Intensity of radiation is proportional to thickness of metal. An auxiliary method employing gamma ray absorption is also discussed. This method is accurate within 3% and has a range between 0 and 0.625-in. thickness. The instrument has been used successfully to locate and measure corrosion in refinery piping storage tanks and other process equipment. It is best suited for examination of flat plates, pressure vessels and pipes of large diameter.

Non-Destructive Methods for Determining Metal Plate Thickness. J. G. Kerley, *Corrosion*, **3**, 467-481 (1947) Oct.

Describes principles and procedures for use of methods utilizing: supersonic vibration; thermal conductivity; magnetic characteristics; electrical resistance; electrical induction; and penetrating radiation (X-rays or gamma-rays). In connection with each instrument, a typical commercial instrument is described. 20 refs.—BLR.

Simple Method for the Detection of Residual Strains in Hardened Steel. (In Russian.) D. M. Nakhimov, *Factory Lab.* (USSR), **13**, 825-832 (1947) July.

Effects of simultaneous exposure to mineral acids in gaseous and liquid form

and application of tensile strain were determined using split rings and wedges. The data from numerous experiments are averaged, charted, tabulated, and discussed. The times required for crack formation and for complete failure are affected by the applied tension more than by the acid strength. 11 refs.—BLR.

Beta-Ray Thickness Gage for Sheet Steel. Otto J. M. Smith, *Electronics*, **20**, 106-112 (1947) Oct.

Tells how G-M counters and integrating circuits, responding to absorption of beta rays by steel strip moving over a radiostrontium source, measure thickness over a range of 7 to 24 mils. Sheets can be sorted automatically by a mechanical gate after cutting. Accuracy is analyzed. —BLR.

Corrosion Beneath Protective Films. J. K. Wirth, *Korros. u. Metallschutz*, **16**, No. 10, 331-8 (1940); *Chim. et Ind.*, **46**, No. 2, 185 (1941).

The electrical resistance of the surface of contact and of the film were measured at intervals for linseed oil paints pigmented with zinc-oxide, red lead, iron oxide, and titanium oxide. The results obtained in this way can be used to explain the variable results obtained with zinc-oxide and iron oxide.—RPI.

METAL FAILURE

The Corrosion of Metals. Part VII—Zinc and Its Alloys. Part VIII—Aluminum and Its Alloys. *Sheet Met. Ind.*, **24**, Nos. 242, 244, 246, 1207-1211; 1633-1636; 2026-2028. In progress. (1947) June, Aug., Oct.

The June installment completes section on zinc, covering galvanic couples, atmospheric corrosion, corrosion by waters and the effect of temperature, zinc in batteries. The following two installments commence account of aluminum: effect alloying constituents, cladding, pitting, and intercrystalline corrosion, stress corrosion.—BNF.

Cylinder Wear in Diesels—What Causes It? How It Can Be Measured. *SAE J.*, **55**, 31-32 (1947) Oct.

Based on five papers presented at SAE Summer Meeting, French Lick, Ind., June 6, 1947. Most important factors are shown to be corrosion, abrasion and scuffing.—BLR.

Crack Detection. *Nature*, **160**, 556-557 (1947) Oct. 25.

Reviews briefly papers presented at symposiums on methods of crack detec-

tion held by the Industrial Radiology Group of the Institute of Physics, July 18-19, 1947.—BLR.

Hydrogen Embrittlement of Steel. Parts II and III. *Metal Ind.,* **71,** 325-329 (1947) Oct. 17; Ibid., 366 (1947) Oct. 31.

Continues discussion of the literature on the above problem.—BLR.

Graphite Formation in Grey Cast Iron. H. Morrogh & W. J. Williams. *Foundry Tr. J.,* **82,** 359-363 (1947) Aug. 21; Ibid., 391-396 (1947) Aug. 28; Ibid., 6-12 (1947) Sept. 4.

An extensive and critical discussion of theories and experimental data available from the literature is followed by a presentation of experimental results obtained by the authors. Illustrated by numerous photomicrographs. 35 refs.—BLR.

REFINERY CORROSION

The Future of Hastelloy Alloys in the Petroleum Industry. C. G. Chisholm, Haynes Stellite Co., Paper before ASME Natl. Conf. on Petro. Mech. Eng., Tulsa, Oct. 7-9, 1946, *Proceedings of ASME Petro. Mech. Eng. Conf. 1946,* 46-47 (Publ. June, 1947).

The principles in selecting the proper Hastelloy alloy (A, B, C, or D) are explained with concrete examples. In general, Hastelloy is chosen where life of other materials is relatively short (one or two years or less) and where continuous operation is essential. Chemicals handled by each type are mentioned. Use of Hastelloy B for lining towers to resist aluminum chloride is an example. Hastelloy C is recommended for strong oxidizing agents. Hastelloy D is used primarily for hot H_2SO_4. Forms in which each alloy is available are given. The Harbison-Fischer Mfg. Co. of Fort Worth supplies Hastelloy D balls with solid Haynes Stellite alloy seats, or stainless seats hard-faced with No. 1 Haynes Stellite alloy rod for oil well pump supply valves.—INCO.

Corrosion Problems in the Petroleum Refining Industry, With Special Problems Experienced in Operation of Solvent Extraction, Dewaxing and Chemical Treatment Plants. J. C. Wood-Mallock, E. S. Sellers & H. Kaye, Manchester Oil Refy. Ltd. Paper before 11th Int. Cong. Pure & Applied Chemistry, London, July 17, 1947. Abst. No. 312/13.

Refinery corrosion problems based on sulfur compounds, naphthenic acids, oxidation, refinery chemicals and cooling

water are discussed briefly. Handling of such special solvents as sulfur dioxide, phenol, etc. are discussed in detail. Evaluations of corrosion resistant materials are summarized.

SURFACE PREPARATION

Vinyl-Resin-Base Wash Primer. Anon., *Paint, Oil & Chem. Rev.,* **110,** No. 7, 45 (1947).

A solution of a vinyl butyral resin in alcohol pigmented with zinc chrome is reacted with phosphoric acid to produce a corrosion-inhibiting coating over which conventional synthetic resin paints can be applied. The primer dries to recoating condition in 10-20 mins. and gives temporary protection to the metal between cleaning and application of the final paint coatings.—RPI.

Treatments for Metal Surfaces Prior to Painting. E. F. Hickson & W. C. Porter, *Prod. Eng.,* **18,** 128-130 (1947) Aug.

Describes equipment for spray chamber process and gives direction for treatment of steel; galvanized metal and sheet zinc; aluminum and aluminum alloys; lead; copper and brass; and magnesium alloys. —BLR.

Pore Size in Protective Films by Electrographic Printing. W. E. Shaw & E. T. Moore, National Lead Co., *Ind. & Eng., Anal. Ed.,* **19,** No. 10, 777-9 (1947) Oct.

A satisfactory technique for the electrographic printing of pores in protective films involves the use of a sandwich consisting of metal pressure platens, a sheet of inhibition paper in contact with the area of coated metal to be studied, and the proper electrolyte. The pressure, voltage and time as well as the developing agent necessary are important for proper printing. The electrolyte used for ferrous metal is 0.5% potassium nitrate, and the developing agent is a mixture of potassium ferrocyanide and ferricyanide. This procedure will be useful in determining porosity in protective coatings on a quantitative basis.—CEC.

Influence of Movement on Corrosion. F. Wormwell, *Iron & Coal Trades Rev.,* **153,** 1196 (1946) Dec. 27; *Corros. & Matl. Prot.,* **4,** No. 3, 24 (1947) May-June.

Gives results of investigation with a rotating-specimen technique, using one-inch diameter mild-steel specimens at speeds up to 260 revolutions per minute

immersed in various media. In 0.5 normal sodium - chloride solution the corrosion rate at 2 rpm is 3 times and that at 260 rpm only 12 times the rate in a stagnant solution.—INCO.

Corrosion-Test Humidity Cabinet. *Instr.* 20, No. 8, 746, 748 (1947) Aug.

New "Precision Corrosion Test Humidity Cabinet" is designed for testing corrosion of materials intended as corrosive preventives. It produces a moisture-saturated atmosphere with continuous condensation on test specimens, in accordance with Army-Navy Aeronautical Standard Specification No. AN-H-31; may also be used for other tests where samples must be submitted to extreme temperature-humidity conditions. Full description. Mfg. by Precision Scientific Co., Chicago.—INCO.

Sheet Pile Corrosion at Port of Copenhagen. Mogens Blach & Axel Rogberg, *Engr.*, 183, 348-350 (1947) Apr. 25.

Gives results from an extensive study of corrosion of steel-sheet piles. Measurements were made both of the reduced

thicknesses of actual piles, and of the reduced weights of test specimens immersed for periods as long as 21 years. Results are charted and discussed and the economics of using thicker sheet calculated. —BLR.

X-Ray Diffraction Studies of Electrodeposits. T. Voyda, *Amer. Electropl. Soc. Proceedings,* 33rd Annual Conv., 33-48 (1946) June.

Notes on the application of X-ray diffraction in the investigation of plating problems at Pratt and Whitney Aircraft. Diffusion of indium into lead (used in bearing production) is examined in considerable detail. Investigation of bonding of electrodeposits to base metals, and electrodeposited alloys are reported. —BNF.

UNDERGROUND CORROSION

Corrosion - Preventive Cable-Pulling Lubricants for Lead-Sheathed Cables in Underground Ducts. H. S. Phelps & F. Kahn, Philadelphia Electric Co., *Corrosion,* 4, 37-44 (1948) Feb.

Corrosion of lead-sheathed power cables in underground ducts may be minimized by use of a suitable corrosion-preventive pulling compound properly applied to the cable. To qualify for this use, the compound must possess an unusual combination of properties that are required and presents performance test specifications for preliminary determination of probable acceptibility.

Corrosion Surveys. M. E. Parker, Jr., Pan American Pipe Line Co., Paper before 1st Ann. Short Course in Gas Technol., Texas A. & I. College, Kingsville, Tex., Aug. 27-29, 1946; *Petro. Eng.*, **18**, No. 10, 270 + (1947) July.

The major types of surveys in relation to corrosion control of pipelines and their principal functions are described. Following are discussed: (1) preliminary or exploratory survey, (2) electrical survey of line already laid, and (3) survey of line that has been placed under protection. Other special surveys such as determining suitable sites for anode beds are considered. Quantities to be measured and the various instruments used are dis-

cussed. A method of recording data is presented.

WATER CORROSION

Ice Rink Piping Fails During Wartime Shutdown. P. S. Park, A. M. Byers Co., *Heat., Piping & Air Cond.*, **19**, No. 4, 97 (1947) Apr.

From visual inspection of the failed piping it was evident that corrosion had progressed from inside to outside of coils. Chemical analysis of corrosion products revealed a substantial proportion of chlorides and calcium oxide indicating conclusively that a breakdown of the calcium chloride brine in the presence of air and moisture had occurred, setting up an acid condition. During the skating season, the pH of a brine solution should be maintained in the 8.0 to 9.0 range, with 8.5 being a desirable minimum. As added protection, use of the chromate type of treatment is suggested involving the use of chromate compounds which act as corrosion inhibitors through the formation of a stable, adherent, and nonporous film on the surface of the metal. During the nonoperating season, the brine system

should be kept full of alkaline brine with periodic tests being made at frequent intervals to ascertain the pH of the solution.—INCO.

Materials in Boiler Feed-Pump Construction. H. L. Ross, Allis-Chalmers Mfg. Co., Paper before Midwest Power Conf. (1947) ; *Combustion*, **18**, No. 10, 43-44 (1947) Apr.

Author reviews the influence of various factors on corrosion-erosion when employing carbon steel among which are low pH of the feedwater and addition of sodium sulphite. Use of corrective materials for pump parts discussed.

Electrical Deaeration Licks Corrosion in This Plant. V. Rodwell, *Power*, **91**, No. 5, 92-94 (1947) May.

Laboratory tests showed such promising results that the power plant deaerators at Slough Estates, Ltd., England, were revamped and electrodes installed so boiler feedwater could be treated electrically. Basic treatment, corrective measures, test results, plant application, process operation and operating results are discussed.—INCO.

Mechanism of Corrosion of Water Pipes. Thomas M. Riddick, *Water & Sewage Works*, **94**, R149-R154 (1947) July.

Discusses above mechanism and presents three empirical formulas derived to express numerically the corrosive tendencies of water from analyses. Illustrated by photographs of corroded pipes, etc.—

Corrosion Resisting Steel—Use of Hadfields "ERA 172" for Marine Conditions. *Iron & Steel*, **20**, No. 136 (1947) April; Mond Gen. Ref. Sheet, Ser. No. 523, 25 (1947) April 12.

Service data on a chromium-bearing steel of unspecified composition, under exposure to marine conditions in various parts of the world. The information is stated to be based on service records extending over 17 years. The steel is stated to have a yield strength of 14 tons per square inch and a tensile strength of 26 tons with elongation of the order of 40 percent—INCO.

Aspects of Corrosion of Metals and Alloys—Part I. D. S. Naidu, *J. & Proc. Inst. Chem.* (India), **17**, 162-172 (1945); Chem. Abs., **41**, No. 6, 1591 (1947) March 20.

Reviews the problem of corrosion under the special conditions prevailing in India. Corrosion cases were investigated. Mentioning most theories of corrosion he favors and summarizes the electrochemical theory. The corrosion of food utensils is given special mention. A program of investigation is outlined. Agents usually causing corrosion and specific cases investigated are listed.—INCO.

Corrosion and Oxidation Experiences in High Pressure and High Temperature Stream Service. P. M. Brister & J. B. Romer, Babcock & Wilcox Co., Paper before 91st Gen. Mtg., Electrochem. Soc., April 9-12, 1947, Louisville, Ky. Electrochem. Soc. Preprint 91-17 (1946).

Deals with the corrosion experienced with metals used for steam generating tubes and superheater tubes for high pressure boilers. Methods of relief and interpretation of the causes of corrosion of steam generating tubes are presented. For high temperature super-heater tubes it is shown how temperature shock affects the rate of corrosion on the steam side and gas side of the tube. With the proper selection of ferritic type chromium-molybdenum steel alloys, steam and flue gas corrosion is not troublesome

for metal temperatures up to about 1200° F. Stainless steels are satisfactory for temperatures somewhat above 1200° F. For structural members, such as hangers and supports, chrome nickel steel alloys are preferred for elevated temperature service.—INCO.

An Evaluation of Test Methods for the Determination of Dissolved Oxygen in Deaerated Boiler Feedwater. J. F. Sebald, Worthington Pump & Machinery Corp., *ASTM Preprint* No. 118, 17 pp. (1947).

Four test methods generally accepted as reliable were considered for evaluation as to performance: Winkler, Schwartz-Gurney "A," Schwartz-Gurney "B" and the U. S. Navy Laboratory modification of the Schwartz-Gurney "A". Area of investigation, selection of analytical equipment, test site, and mechanical equipment, test program and its results are described. 11 refs.—INCO.

Some Methods for Studying the Behavior of Alloys in Sea Water at High Velocity. F. L. LaQue & W. C. Stewart, *Typescript,* 16 pp. (1947).

Describes certain types of apparatus and methods of test used by the authors and their research associates in studying the behavior of metals and alloys when

they encounter salt water moving at high velocity. E ES rotating disc erosion testing machine; submerged horizontal disc erosion testing machine ("whirligig"); aspirator-type jet impingement test apparatus. Tests on cupro-nickel, G-bronze, hydraulic bronze. Purpose of paper is to demonstrate use of the testing methods and the ability of the different devices to throw light on effect of factors such as velocity, temperature, aeration, salinity and nature of water.—BNF.

Corrosion and Embrittlement of Boiler Metal at 1350 Pounds Operating Pressure. L. E. Hankinson & M. D. Baker, *Trans. ASME,* **69,** 479-486; discussion, 500-503 (1947) July; *Combustion,* **18,** No. 6, 44-45 (1946) Dec.; Ibid. **18,** No. 9, 39-42 (1947) Mar.

After seven years of operation, three 1350-psi. boilers at the Springdale Station (West Penn Power Co.) developed a type of barnacle corrosion and metal embrittlement which caused considerable apprehension regarding the safety and continuous operating ability of these boilers. Corrective steps included reduction of the dissolved oxygen content of the feedwater to 0.02 ppm or below, maintenance of sulfite at 3 to 10 ppm in the boiler water and reduction of the ammonia content of the feedwater which lowered the amount of copper and its compounds in the boiler sludge. As a result, the barnacle development and metal embrittlement stopped. It was concluded that the barnacle growth and embrittlement stopped when sulfite feeding was resumed. The reduction of oxygen in feedwater was helpful.

Steam Turbine Blade Deposits. F. G. Straub, Univ. of Ill., *Univ. of Ill. Engr. Exper. Sta. Bull.* Ser. No. 364; *Univ. of Ill. Bull.,* **43,** No. 39, 92 pp. (1946) June 1.

A summary of studies to determine the causes of steam turbine blade deposits. Types of deposits are classified, a study of solubility of salts in high pressure steam is reported, and tests are described which showed that silica distills off from boiler water in appreciable amounts above 660 lbs. psi. It is proposed that silica concentration in the boiler water in higher pressure boilers should be held below 10 ppm. A method for determining small amounts of silica in steam is also described.—INCO.

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